5-2018

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Benjamin A. Loseke
*University of Nebraska-Lincoln*

Loseke, Benjamin A., "Replacing Herbicides with Groundcovers to Enhance Vineyard Sustainability" (2018). *Theses, Dissertations, and Student Research in Agronomy and Horticulture*. 138.
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# REPLACING HERBICIDES WITH GROUNDCOVERS TO ENHANCE VINEYARD SUSTAINABILITY

by

Benjamin A. Loseke

A DISSERTATION

Presented to the Faculty of
The Graduate College at the University of Nebraska
In Partial Fulfillment of Requirements
For the Degree of Doctor of Philosophy

Major: Agronomy and Horticulture

Under the Supervision of Professor Paul E. Read

Lincoln, Nebraska

May, 2018

# REPLACING HERBICIDES WITH GROUNDCOVER TO ENHANCE VINEYARD SUSTAINABILITY

Benjamin A. Loseke, Ph.D.
University of Nebraska, 2018

Advisor: Paul E. Read

In many Midwestern vineyards a three to four-foot weed-free strip is maintained directly beneath the vines to reduce vine-weed competition. Conventionally, this strip has been conserved with repeated applications of herbicide, mainly glyphosate. The necessity for this weed-free strip to reduce vine-weed competition has been well documented in more arid climates. However, in areas with higher soil fertility and adequate rainfall, this strip may be unnecessary. Moreover, stand establishment and early vine growth have not been well documented when planting groundcovers (GC) immediately following the vine planting. The main objective of this project is to assess the severity of competition for water between 'Edelweiss' grapevines and neighboring permanent GC treatments. In year one (2014), the vineyard and GCs were established, where the GCs were planted immediately after the vines. Midday leaf water potential ($\Psi_{md}$) measurements began in 2015 and lasted through 2017 to assess water competition between vines and GCs. Additional data collected during the four year project included: pruning weights, bud break, yield and fruit quality and soil nutrition. Generally, GC treatments had lower $\Psi_{md}$ than the herbicide sprayed control, however, none of the treatments exhibited even slight water stress. Vine-GC competition was most apparent in the three years of pruning weights, where the most native grass GC treatment had up to 99% in 2014, 193% in 2015 and 183% in 2016 lower weights than the control. Harvest in 2016 and 2017 showed significantly lower yields between GC treatments and the control. However, no differences were found in berry quality (pH, Titratable Acidity, °Brix). An additional greenhouse project was done to define water stress thresholds for ‘Edelweiss’ grapevines using $\Psi_{md}$ and high resolution thermal infrared images. Fully irrigated and 14-day dry vines exhibited a $\Psi_{md}$ of -8.7 bars and -13.3 bars, respectively. The grapevines exhibited a mild, moderate and severe water stress level at 8, 10 and 12 days-dry, respectively ($\Psi_{md}$ of -12 bars, -12.5 bars and -13 bars). Results suggest that planting groundcovers in both the alleyways and in-row areas of the vineyard during the first year of establishment is detrimental to vine growth and causes reduced yields.

*This dissertation is dedicated to Jess, Theodore, Brooks and my late Grandfather Keith Ticknor.*

# ACKNOWLEDGEMENTS

I would like to thank my Adviser, Paul Read, for walking with me through my M.S and Ph.D journey. The wealth of knowledge and wisdom you have shared over the last several years will stick with me for a lifetime. I must also thank Steve Gamet for spending countless hours with me in the field. This project could not have been accomplished without his assistance.

I would also like to thank my advisory committee, all of whom played a key role in making this a success: Ellen Paparozzi, Charles Francis, Erin Blankenship and Brian Wardlow. Your help along the way is greatly appreciated. The help from the countless graduate students during key periods of the project should not go without gratitude.

This project would never have happened without the generosity of Eric Nelson. He allowed use to complete this project on his commercial vineyard property. In addition, he allowed us to utilize his equipment and vineyard workers when they were needed. His dedication to the Nebraska Grape and Wine Industry is a vital piece of its success.

Finally, I want to thank my family who has stood by my side during this very long process. I couldn't have done this without the encouragement and support of my wonderful wife, loving parents, brothers and grandparents.

Thank You!

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# INTRODUCTION AND REVIEW OF LITERATURE

## INTRODUCTION

With over 280 million pounds of glyphosate being sprayed in the United States annually, chemical weed control in agriculture has become heavily scrutinized due to the extensive use of this specific chemical herbicide. Recently, outrage has surfaced after the World Health Organization issued a statement possibly linking glyphosate to cancer (FRITSCHI et al., 2015). In addition, glyphosate has been linked to many other health issues including Parkinson's disease, infertility and fatal kidney disease (JAYASUMANA et al., 2014). In 2010, more than 400,000 pounds of Roundup were applied to wine grapes (V*itis* spp.) in California alone. The consuming public has voiced their concern over the ever increasing use of herbicides and as a result research investigating chemical-free weed control strategies has become widespread.

The benefits of replacing herbicides with groundcovers in the vineyard extend far beyond just eliminating the use of chemicals and reducing vine vigor. Planting permanent groundcovers in the vineyard has been shown to improve soil erosion protection, water infiltration and organic matter while reducing soil crusting and soil temperature (GREENSPAN, 2015). Soil left bare, whether from herbicide applications or cultivation, increases the intensity of runoff and erosion (BLAVET et al., 2009). Use of groundcovers prevents the direct contact of raindrops with the soil surface, which weakens and breaks aggregates apart, contributing to the formation of surface crusts that reduce water infiltration (EPSTEIN AND GRANT, 1973).

Replacing chemically controlled strips beneath the vines is not an end-all solution for all vineyards. There are a variety of factors that determine which weed control management strategy should be employed in the vineyard. The factors include vine age, vineyard design, climatic conditions, soil texture and fertility, vine age and social and economic considerations such as availability of labor, aesthetics, and public perceptions (BAKER et al., 2005; BAVOUGIAN, 2014; RIPOCHE et al., 2010; THOMSON AND HOFFMANN, 2007). Traditional grape growing regions tend to be situated on well drained – low fertility soils. In these places, a highly water competitive groundcover may have detrimental effects on overall yield and/or fruit quality.

In areas that receive moderate to heavy amounts of rainfall, such as Southeast Nebraska (annual precipitation over 30 inches), and have highly fertile soils overly vigorous growth is common in many winegrape cultivars. Grapevines have an indeterminate growth habit where vegetative growth is not reduced by a shortening photoperiod, but rather continues as long as sufficient heat, nutrients and moisture are available (KELLER, 2010). 'Overly vigorous' is characterized by vines that have large, dense canopies which result in low light penetration (DOKOOZLIAN AND KLIEWER, 1995) and shade the fruit zone which compromises fruit quality. Additionally, excessive shading can delay veraison and fruit maturation, causing reduced soluble solids (°Brix) and anthocyanin concentrations as well as increase the concentration of undesirable flavor compounds such as methoxypyrazines (CHORTI et al., 2010; SCHEINER et al., 2011). Overly vigorous vines may also have a problem not reaching full dormancy in the late fall which can result in reduced cold hardiness (BYRNE AND HOWELL, 1978). Finally, dense canopies reduce air flow as well as light infiltration into the canopy, thus increasing disease pressure and reducing spray penetration and effectiveness of fungicide applications (AUSTIN AND WILCOX, 2011). Shoot and cluster thinning, hedging, leaf removal and lateral shoot pulling are the main methods to increase light and air penetration into the canopy, however these practices require significant amounts of labor and time (SMART AND ROBINSON, 1991).

Maintaining a slight-to-moderate water deficit and thus inducing a certain level of stress can be highly beneficial in grapevine cultivation because it stimulates optimal quality parameters without significantly compromising yield. As a vineyard manager, gauging the level of grapevine water stress can be quite difficult. Several methods have been developed to measure the water potential of grapevines. Traditionally, water status in plants has been evaluated by measuring in-situ soil water status (soil water content or soil water potential) or by measuring in-situ physiological variables that characterize water status in leaves (relative water content, leaf water potential and stomatal conductance). A more recent strategy for assessing water stress is through the use of remote sensing which offers a non-destructive method of quantifying the amount of water present in plants. In this project, infrared thermography (IRT) was employed to attempt to measure the water status in grapevines. Infrared thermography measures the amount of sensible heat released by the leaf during periods of water stress which allows the leaf temperature to exceed the air temperature (ANDERSON AND KUSTAS, 2008; FUCHS, 1990; MCVICAR AND JUPP, 1998). These leaf temperature data are then typically combined with meteorological data to further refine the level of water stress. One of the most widely used indices for quantifying water stress is the Crop Water Stress Index (CWSI) which combines leaf/canopy temperatures with ambient air temperature, relative humidity and/or irradiance (IDSO et al., 1981; JACKSON et al., 1981;

JACKSON et al., 1988) Non-destructive thermal imagery is beneficial because it allows growers to rapidly assess the water status of the vines over a large area.

The following research evaluated five different native grass and legume groundcover mixtures and their effect on neighboring 'Edelweiss' grapevines in a commercial vineyard located in Southeast Nebraska. Groundcovers were established immediately following the planting of the grapevines so that the covers were established simultaneously with the vines, which is atypical to normal practices.

The objectives for the research project were to answer the following questions:

1. How quickly will five different native grass and legume groundcover mixtures establish and reach 100% ground cover?
2. How do the five chosen groundcover treatments compete with newly planted 'Edelweiss' grapevines for water?
3. What impact do these groundcovers have on vine growth, bud break, fruit yield, and fruit quality (e.g. pH, titratable acidity and soluble solids)?
4. What type of insects are present when flowering and non-flowering groundcover mixtures are planted in the vineyard?
5. Can infrared thermography (IRT) be used to assess grapevine water status using the crop water stress index (CWSI) and be correlated to leaf water potential (LWP)?
6. Will a grower-affordable infrared sensor be sensitive enough to measure grape water status?

## REVIEW OF LITERATURE

### GRAPE

The grapevine (*Vitis vinifera*) belongs to the family Vitaceae which comprises about 60 inter-fertile wild species distributed in Asia, North America and Europe under subtropical, Mediterranean and continental – temperate climatic conditions (TERRAL et al., 2010). The genus *Vitis* includes more than 70 species (ALLEWELDT AND POSSINGHAM, 1988) and some of the species currently found in Nebraska include *V. aestivalis Michx.*, *V. cinerea* (Engelm)., *V. riparia Michx.*, and *V. vulpine* L. (KAUL et al., 2006). The North American V. *rupestris*, *V.riparia or V. berlandieri*, are used in breeding rootstock due to their resistance against grapevine pests, such as Phylloxera and mildews (TERRAL et al., 2010).

### ‘EDELWEISS’ GRAPE

‘Edelweiss’ originated in Osceola, Wisconsin and was developed from crosses that date back to 1949 (SWENSON et al., 1980). The pedigree of ‘Edelweiss’ is ‘MN 78’ X ‘Ontario’ (SMILEY et al., 2008). ‘Edelweiss’ was introduced by the University of Minnesota in 1980. It was introduced as a table grape with the goal of improving table grape quality in cold winter regions but then became an important cultivar for white wine, especially when grown in Nebraska (QRUNFLEH, 2010). The ‘Edelweiss’ vine is considered highly vigorous, producing conical shaped clusters that are medium in size, very loose to moderately compact and often double-shouldered. The vine is usually trained to a Geneva Double Curtain (GDC) trellis system. Berries are round, medium sized and green skinned with a white bloom (SWENSON et al., 1980). Berries are also of a slip skin type, have tender flesh and have the lubrusca fruit flavor (BROOKS AND OLMO, 1997). ‘Edelweiss’ breaks bud early, making it highly susceptible to spring freeze. In addition, it is not productive on secondary buds (SMILEY et al., 2008). The juice is relatively low in acidity (0.6-0.8%) and has moderate soluble solids (14-16%) when harvested for wine (SWENSON et al., 1980). It is also known to be an early maturing cultivar and Nebraska grape growers usually harvest 'Edelweiss' in mid-August at 14-15 °Brix (QRUNFLEH, 2010).

## CULTIVATION

The most traditional and popular technique used for controlling weeds throughout the world is still through the use of tillage. Tillage eliminates surface crusts, leading to less run-off than when herbicides are the only means of weed control (MERWIN AND STILES, 1994). The main disadvantages of tillage cultivation in the under-vine area of the vineyard is soil compaction and loss of structure, cumulative loss of fertility and soil organic matter, risk of damage to the vine roots, trunks, and cordons, weed emergence, and contribution to the directional spread of soil pests and pathogens (MERWIN AND STILES, 1994; SALAZAR AND MELGAREJO, 2005; STEENWERTH AND BELINA, 2008a).

A study in Bordeaux, France on dry-farmed Cabernet Sauvignon, Sauvignon blanc and Merlot planted to a tall fescue cover crop (*Festuca arundinacea*) regime reduced vine vigor, yields, leaf nitrogen and juice nitrogen (RODRIGUEZ-LOVELLE et al., 1997). In another study, three of four sites in France also showed lower yields under cultivation than to other vineyard floor management practices (GAVIGLIO, 2007). This result was attributed to reduced nutrient uptake due to damage to surface roots of the grapevine by cultivation equipment.

## HERBICIDES

The most common method of controlling weeds in the United States is through the use of "burndown" herbicides, such as glyphosate. However there are many documented advantages and disadvantages of using such herbicides. A major advantage is their specificity to certain weed species, their low cost and ease of use, whereas the main disadvantages include the risk of developing resistant weeds, risk of toxicity to both the operator and the vines and the potential of these chemicals polluting surface and groundwater resources (MERWIN AND STILES, 1994; TOURTE et al., 2008). There are also some indirect effects which include soil compaction during application and decreased soil fertility from loss of soil organic matter (SMITH et al., 2008; STEENWERTH AND BELINA, 2010).

Recently, work has begun to limit off-target interaction with herbicides applied in the vineyard. Herbicides are used at the lowest possible dosage and sprayers can be equipped with infrared sensors that detect weeds and limit the amount of herbicide applied (GAVIGLIO, 2007; SALAZAR AND MELGAREJO, 2005). In a five year study on California's central coast, the economics and efficacy of weed control practices were evaluated. Post emergence (burndown) herbicides required fewer applications than preemergence herbicides or cultivation and provided similar results, while being less costly. Coupling both preemergence (diuron, oxyfluorfen) and postemergence (glyphosate) herbicides has been shown to be the least expensive and most effective method of controlling weeds in Lodi, California vineyards (ELMORE et al., 1997). When cultivation was done in the fall, coupled with a single postemergent herbicide treatment in a Napa California vineyard, a level of weed control similar to two herbicide treatments was observed. This program used half the amount of herbicide (BAUMGARTNER et al., 2007).

Resistance has become a main area of concern regarding the use of herbicides in all areas of agriculture. Horseweed (*Conyza Canadensis*) (SHRESTHA et al., 2010) and Italian ryegrass (*Lolium multiflorum*) (JASIENIUK et al., 2008) have both shown glyphosate resistance in California. As of 2012, 348 resistant biotypes and 194 weed species were shown to be resistant to herbicides (GUERRA AND STEENWERTH, 2012). There are countless studies looking at the effect of herbicide resistant species in row cropping situations but very few have addressed the problem in winegrape vineyards.

As a result, a shift in weed communities is beginning to take place. Annual weed populations have been effectively controlled by herbicide, however, perennial weed populations have begun to take hold and have been shown to be more difficult to control (ELMORE et al., 1997). A shift in weed communities can result from a couple of different factors including the herbicide mode of action and the timing of application (BAUMGARTNER et al., 2007; SANGUANKEO AND LEÓN, 2011).

Increased public concern regarding the toxicity and long-term health effects of herbicides has spurred the development of organic herbicide type products (ELMORE et al., 1997; TOURTE et al., 2008). A number of organic herbicides have been accepted for use in organic agriculture and include: acetic and citric acid, clove oil, ammonium nonanoate, and corn gluten meal (BAVOUGIAN, 2014; LANINI, 2011). Organic herbicides tend to have different application instructions compared to conventional herbicides in order to increase their effectiveness. To improve weed control, organic herbicides should be applied at higher rates, include an organically-certified surfactant, be applied during warm periods and when weeds are at young stages. A major problem with organic herbicides is that they are relatively ineffective against grasses and weeds that posses waxy or pubescent leaves. A study in California comparing different methods of weed control found differences in control but no differences in vine growth, yield or fruit quality; suggesting that *complete* control of weeds in the vineyard is not only unrealistic but unnecessary (SHRESTHA et al., 2012).

To control weed germination and seedling growth, herbicides have been combined with mulches. In Lodi, California, a mulch consisting of fresh residues of wheat (*Triticum aestivum*), oats (*Avena sativa*), and barley (*Hordeum vulgare*) grown in interrows and chopped and transported to the vine rows showed to be effective at limiting seedling germination and growth (ELMORE et al., 1997). Allowing the cover crop to mature and increase in biomass and then burning-down and desiccating the cover crop to act as mulch is another option. A desiccated cover-crop mulch in an Indiana vineyard provided better weed suppression than when the same cover crop was either mowed or incorporated into the soil (BORDELON AND WELLER, 1997).

The effects of vineyard floor management on the grapevine may not be apparent in the short term but may be in the long term when grapevines have significant nitrogen (N) stores. This is especially true when N fertilization is part of the management system (SCHREINER et al., 2006; SMITH et al., 2008). Weed management practices not only affect vine N composition but also soil N availability. A five year study in a Chardonnay vineyard in the Central Coast of California showed greater nitrous oxide emissions and nitrate leaching when weeds were chemically controlled with a herbicide than from cultivation that supported greater vegetation cover (SMITH et al., 2008; STEENWERTH AND BELINA, 2010). However, the grapevines showed similar leaf and petiole nutrition over the five-year trial. This suggests there were changes in soil characteristics related to soil N availability and was confirmed by the high N stores in the grapevines.

Herbicides can not only provide weed control, they can also be used to control periods of competition between the cover crop and the vine. In a South African vineyard, a postemergence herbicide was applied to specifically eliminate competition from a cover crop just before or after bud break and showed increased shoot biomass and crop yields (FOURIE et al., 2006). This practice can also be useful in establishing new vineyards, where it can help accelerate the young vine development by freeing the vines from unnecessary competition. A contrasting study conducted in Croce, France showed decreased yields when native vegetation was killed before (March) or after (June) vine budbreak (GUERRA AND STEENWERTH, 2012). This can be explained by the decomposing cover crop causing microbial N immobilization and limiting soil inorganic N required by the vine during budbreak. However, a cover crop not burned-down until after bud break could sequester N and compete with the vines for water (CELETTE et al., 2009; STEENWERTH AND BELINA, 2008a). The vines growing amongst the cover crop that was burned-down after budbreak produced wine higher in alcohol, total polyphenols, anthocyanins and lower in acidity. These wines were judged to be superior compared to wines produced with a cover crop desiccated before bud break. This suggests that for vine-cover crop competition to negatively affect wine quality, the cover crop growth must be prolonged during most of the growing season.

Generally speaking, non-organic herbicides are more effective at controlling vineyard weeds than cultivation or other non-conventional methods. Herbicides are also more cost effective when compared to other methods and are included in most vineyard weed management schemes.

## COVER CROPS

Cover crops are widely used in viticultural areas which have high summer rainfall, mainly to prevent soil erosion and allow access into the vineyard with machinery (LOPES et al., 2004). Other benefits of establishing groundcovers in the vineyard include: improved water infiltration and water-holding capacity, improved soil structure and prevention of crusts, increased fertility and organic matter, vine growth regulation, weed suppression and improved wine and juice characteristics. Cover crops are also beneficial to the environment by reduced nutrient leaching, increased biodiversity and microbial biomass, and reduced herbicide inputs (ALJIBURY AND CHRISTENSEN, 1972; BAVOUGIAN, 2014; GUERRA AND STEENWERTH, 2012; GULICK et al., 1994; LOPES et al., 2004; MONTEIRO AND LOPES, 2007; NICHOLLS et al., 2000; SMITH et al., 2008).

A major hurdle for cover crop use in the vineyard is the increased water and nutrient competition that takes place between the cover crop and grapevine. However, this competition may also be beneficial if soils are deep and soil moisture is excessive and/or in areas where vines are overly vigorous. Other disadvantages include increased labor and costs associated with management, increased risk of spring frost due to changes in the radiation balance and damage to the vines from higher rodent populations (CELETTE et al., 2009; CELETTE et al., 2008; INGELS et al., 2005). A foremost challenge of managing cover crops in the vineyard is treating it also as an income producing crop. Care must not only be given to the vines but also the cover crops and they should be treated as an integral part of the vineyard system. For example, irrigation and fertilization practices may need to be altered to meet the needs of both the cover crop and the vines (COLUGNATI et al., 2004; LAKSO et al., 2008).

A distinction should be made between cover crops and groundcovers. A cover crop is considered to be an annual or biennial "cover" that is intended to cover the ground for only a portion of the year (BAVOUGIAN, 2014). After being desiccated, it is typically tilled in to benefit the soil. A groundcover refers to a permanent or perennial herbaceous plant that covers the ground throughout the entire year and flourishes year after year.

The most frequently used cover crops belong to the Poaceae family (cereals or grasses) and the Fabaceae family (legumes). Other cover crops that are used more often in arid areas are the forbs found in families such as Brassicaceae and Asteraceae (MCGOURTY AND REGANOLD, 2005). Since vineyards are established in many different areas and climates a variety of species have been adapted for use as cover crops and groundcovers with over 50 plant species used in California alone. (INGELS, 1998). Different species can each benefit the vineyard in a variety of ways. For example, grass species have extensive fibrous root systems that reach deep into the soil and contribute much organic matter to the soil, as well as reducing compaction and improving soil structure. They also tend to have slower decomposition rates than many other types of vegetation due to their high C:N ratio compared to legumes which have a much lower C:N ratio (COLUGNATI et al., 2004; MCGOURTY AND REGANOLD, 2005). Legumes can be highly beneficial as they are able to fix atmospheric nitrogen into the soil and help meet the microbial N needs (FOURIE et al., 2006; MCGOURTY AND REGANOLD, 2005). The amount of atmospheric N fixed by legumes depends on type, inoculation effectiveness, soil moisture and temperature (MADGE, 2005). Strawberry clover (*Trifolium fragiferum* L.) has been shown to have one of the highest N fixation rates, ranging from 100 to over 330 kg/ha where vetches (*Viciasp.*) generally fix 50 to 220 kg/ha N (INGELS, 1998). While legumes contribute nitrogen to the soil once tilled into the soil, rye and triticale decrease nitrogen, sodium and phosphorus concentrations compared to a bare soil treatment (SMITH et al., 2008). Permanent perennial groundcovers have been shown to compete for nitrogen more strongly than nonpermanent barley cover crops and permanent perennial groundcovers reduced nitrogen content in grapevine storage organs, which influenced the current and following years' nutrition levels. A greater effect was noticed in years when water was a limiting factor (CELETTE et al., 2009).

Permanent groundcovers are best suited for soils with high water holding capacity and fertility or sites with abundant rainfall due to potential vine-groundcover water competition.

This is especially true in non-irrigated vineyards (COLUGNATI et al., 2004). A groundcover does not necessarily need to be planted; it can easily be introduced by continually mowing the naturally present plant species. This practice tends to favor the grass species as the continuous mowing discourages the growth of the broadleaf species (LIPECKI AND BERBEĆ, 1997). Alternatively, groundcovers can be seeded directly into the vineyard (typically once the vines have been established) or the natural reseeding of annuals can flourish year after year. Reseeding annuals can be problematic, as they have imperfect seeding and will not typically cover the vineyard floor until a large seedbank is achieved (MCGOURTY et al., 2008). Mowing legume groundcovers and cover crops during establishment at the flowering stage tends to promote rapid soil coverage (COLUGNATI et al., 2004). Permanent grass groundcovers consisting of grasses will typically benefit from nitrogen fertilization, especially with taller species that compete with the grapevines (AGULHON, 1996; CARSOULLE, 1995; COLUGNATI et al., 2004; SPRING AND MAYOR, 1996). Due to the symbiotic growing relationship between permanent groundcovers and the grapevines, groundcovers tend to impact vine growth and quality to a higher degree than non-permanent cover crops.

The greatest concern regarding the use of cover crops and groundcovers is amount of water consumption by species other than the vines. Higher leaf transpiration rates were observed in weed species compared to 25-year-old Riesling vines in a German study (LOPES et al., 2004). Cover crop species generally have higher transpiration rates than grapevines. For example, a stand of common mallow (*Malva neglecta*) contributes as much as 5 mm $H_2O$ $d^{-1}$ whereas, vine transpiration rates fall around 0.9 mm $H_2O$ $d^{-1}$. Also interesting, is that the peak water consumption between vines and cover crops is quite different. Cover crop species water consumption peaks between 12 and 15 hours into the day while the grapevines peaked earlier, between 8 to 10 hours (GUERRA AND STEENWERTH, 2012).

A common practice to achieve multiple benefits from a cover crop or groundcover is to plant a mix of grasses, legumes and forbs (GUERRA AND STEENWERTH, 2012). There are several studies comparing cover crop mixes and their effectiveness in different soil types, topographies and climates (BREIL, 1999). Deep soils with high water availability or areas with high rainfall can support a more aggressive mix, whereas a steep hillside and a limited moisture vineyard would call for a mix with more fescue species (*Festuca* spp.). Soil N mineralization and nitrification rates associated with decomposition of single species grown alone are not necessarily additive when grown in a mixture (EVINER AND HAWKES, 2008), revealing a need for more research on effects of these occurrences on vine growth and N storage (GUERRA AND STEENWERTH, 2012).

## CULTURAL AND BIOLOGICAL IMPACTS OF COVER CROPS AND GROUNDCOVERS

An often overlooked benefit of establishing cover crops or groundcovers in the vineyard is the increased habitat diversification, which favors increased populations of beneficial arthropod species. By increasing species diversity, groundcovers and cover crops may stabilize the ecosystem and enhance the natural control of pests by bringing pest-predator relationships into balance (SULLIVAN, 2003). For example, cutworms prefer to feed on broadleaf plants more than on grasses, and the presence of a broadleaf cover crop may reduce the number of cutworms feeding on grape buds early in the season (OLMSTEAD, 2006).

Cover crops can also be manipulated to achieve certain results from beneficial insects, such as waiting to till in the cover crop, in the previous example, until the threat of cutworm damage has passed.  Mowing the alleyways has also been shown to move the predatory and parasitoid insects into the grape canopy where they feed on the vine (SHAPOSHNIKOVA et al., 2012). Planting cover crops and groundcover mixtures that bloom throughout the season have been shown to harbor beneficial insects for longer periods of time.  In California vineyards and orchards, cover crop systems had lower population densities of insect pests and less damage to fruit, as well as increased numbers and diversity of beneficial insects (ALTIERI AND SCHMIDT, 1985).  However, a permanent groundcover of subterranean clover (*T. subterraneum*) in central Italy lowered beneficial insects in the first year, but increased them the second year through the increase of organic matter in the vineyard (FAVRETTO et al., 1992).

Below-ground beneficial organisms can also be impacted by planting cover crops and groundcovers.  Within three years of planting a groundcover in two Australian vineyards, a drastic increase of beneficial parasitic nematodes and a decrease of plant parasitic nematodes was observed in the soil (RAHMAN et al., 2009).  Cover crops also reduced the incidence of *Botrytis* by reducing soil water content and opening up the vine canopy (DAVID et al., 2001; MORLAT AND JACQUET, 2003; TESIC et al., 2007).  Mammalian rodent species populations have been shown to increase when planting clover in the California Central Valley (INGELS et al., 2005), which will dig underneath the vines and damage roots.  In some cases choosing the proper cover crop hinges on what type of insects feed on it.  For example the Glassy Winged Sharpshooter is a vector of Pierce's disease and feeds on many plants that are typically used in cover crop and groundcover mixtures.  Choosing plants that are not a food source for this insect should be taken into account (MCGAHA et al., 2007).

There are some cover crop species that have revealed a weed suppressive effect due to the release of toxic isothiocyanates after being tilled into the ground.  This has been most often observed in Brassicaceae cover crops, such as kale (*Brassica* spp.), arugula (*Eruca* spp.) and mustard (*Sinapis* spp.) (ANGELINI et al., 1998). Sometimes mustard cover crops are grown before vineyard establishment as a biofumigant when conventional chemical fumigation is unwanted (MATTHIESSEN AND KIRKEGAARD, 2006; OLMSTEAD, 2006). The amount of weed suppression is highly depend upon the species and cultivar planted. For example, rye (*Secale cereale*) releases allelopathic compounds (BARBERI, 2002) and sorghum (*Sorghum* spp.) contains sorgoleone, which reduces weed seed germination (DUKE et al., 2000). However, the weed suppressing ability of legume species is typically low compared to grasses (BARBERI, 2002). A study in Iowa, USA showed better weed control using herbicides rather than the cover crop creeping red fescue in May and June. However the cover crop provided better weed control than the herbicide in July. In addition, under-vine creeping red fescue provided better weed control than cultivation (WASKO, 2010; WASKO AND NONNECKE, 2008).

Cover crops and groundcovers can enhance soil properties in a variety of ways, including increased water infiltration, increased soil nitrate and ammonium pools, and nitrogen mineralization rates (CELETTE et al., 2008; STEENWERTH AND BELINA, 2008b). Increased soil organic matter is often a benefit of planting cover crops in addition to improving soil structure and the depth of low bulk density soil (WHEATON et al., 2008). Decomposing legumes or other cover crops also provide nitrogen to the grapevines, which can be especially important in the early part of the season when nitrogen demand is the highest. Incorporating or mowing the cover crops can be timed to release nitrogen at key vine growth stages (BAVOUGIAN, 2014; PATRICK et al., 2004). Groundcovers and cover crops are also used to reduce soil erosion in vineyards planted on sloping terrains. These result from the increased water infiltration into the soil and conserve topsoil and protect surface water (ALJIBURY AND CHRISTENSEN, 1972). A study in a

Brazilian table grape vineyard, reported better soil quality in cover crop plots that were mechanically mowed rather than burned down with herbicide (ROSA et al., 2013). Mowing may also reduce competition between the vines and cover crops because mowing has been shown to temporarily decrease evapotranspiration of fescue cover crops (CENTINARI et al., 2013).

Grapevine roots have been shown to occupy more shallow soil depths when grown alongside groundcovers under non-irrigated conditions (VAN HUYSSTEEN, 1988). Which may decrease the vines' ability to withstand drought periods. Studies conducted in Bordeaux, France in the 1980s showed that groundcovers reduced vine vigor, yield, leaf N and *Botrytis* infection (CARSOULLE, 1995). More recent studies have confirmed these results, showing that permanent groundcovers have a devigorating effect on neighboring vines. This was well documented in a 17-year study in the Loire Valley, France where a permanent tall fescue stand inhibited vine growth, lowered pruning weights and lateral shoots, and eventually decreased yields. However, increased canopy exposure and fruit temperature was observed and reduced *Botrytis* incidence resulted (MORLAT AND JACQUET, 2003). In an extensive vineyard cover crop project in Indiana, nine cover crop treatments were planted alongside newly established and irrigated grapevines. Plants in the best cover crop plots had 30% less leaf area, 25% fewer leaves, 50% less shoot dry weight and 50% less root dry weight than weed-free control vines. Fall planted cover crops limited vine growth more than the same cover crops planted in spring (BORDELON AND WELLER, 1997). In a Swiss study, berry, cluster and pruning weights were also reduced by a tall fescue (*F. arundinacea*) cover crop. Vine foliage density was decreased and caused vine growth to stop earlier than did the herbicide control and low fescue (*F. rubra*) (DAVID et al., 2001). Water competition between cover crops and vines should also be considered. Under-vine creeping red fescue reduced stem water potential and petiole nitrogen concentration at bloom, reduced the number of leaf layers by 21%, and reduced cane pruning weight by 47% compared to the herbicide control (HATCH et al., 2011). Alleyway groundcovers reduced predawn leaf water potential of ‘Cabernet Sauvignon’, but yield and fruit chemistry were unaffected during the first two years. In the third year, vine vigor was reduced and improved juice quality was observed (LOPES et al., 2008).

Reduced vine vigor induced by cover crops may be desirable in regions where vines tend to be excessively vigorous, which can cause self-shading and reduced vine-balance (WHEELER et al., 2008). It has been shown that groundcovers and cover crops can be a valuable tool to control overly vigorous vines by competing for water, nutrients and other resources (GIESE et al., 2010; HATCH et al., 2011; TESIC et al., 2007). A permanent groundcover can also improve soil physical properties and juice quality (MORLAT AND JACQUET, 2003). In an Australian vineyard, canopy openness increased and shoot length decreased with increasing soil coverage by permanent groundcovers. Reduction in berry weights, cluster numbers and yield was not noticed until three years after groundcover establishment (TESIC et al., 2007). These results were more pronounced in dry, arid sites than in cool, humid sites, suggesting that irrigation and fertilization practices may compensate for establishment of groundcovers in warm climates (GUERRA AND STEENWERTH, 2012). CASPARI AND MONTANO (2013) reported as much as an 80% decrease in pruning weights when planted with inter-row rye grass and chicory cover crops, however total yields were not affected. Nutrient competition has also been demonstrated in a Spanish ‘Tempranillo’ vineyard where vine vigor was reduced through a reduction in nitrate availability (PÉREZ-ÁLVAREZ et al., 2013). In an irrigated California vineyard, no-till treatments reduced petiole nitrate but tillage and cover cropping did not affect yields (STEENWERTH et al., 2013).

Vine devigoration is not a universal response in groundcover and cover crop studies. In a 10-year study in South Africa the cover crop was burned down before bud break and vines with this treatment showed the highest plant and juice nitrogen levels at harvest (FOURIE et al., 2006). However in areas where excessive vigor can be problematic, higher N levels may be undesirable. To compensate for this FOURIE et al. (2006) recommended rotating N-scouring grass species with legumes to decrease soil N levels. A study in Oregon with established 'Pinot Noir' vines demonstrated that they were unaffected by 5 different cover crop treatments when compared to clean cultivation. No differences were found among pruning weights, leaf water potential (LWP), soil water content, fine root density, shoot growth, yield and cluster weight, or juice quality (SWEET AND SCHREINER, 2010). Likewise, in-row cover crops did not affect yield, pruning weight, berry size, or midday stem water potential in New York.

### IMPACT ON JUICE AND WINE QUALITY

Effects on wine and juice quality can mostly be attributed to competition that exists between cover crops and grapevines for nutrients and water which overall leads to a less dense canopy and increased fruit exposure (AFONSO et al., 2003; DAVID et al., 2001; TESIC et al., 2007; WHEELER et al., 2005). Other impacts of vine-cover crop competition include reduced berry size and yield, lower ambient/canopy temperature and increased *Botrytis* incidence caused by the increased canopy humidity from cover crop transpiration (MORLAT AND JACQUET, 2003; NAZRALA, 2008). When using permanent cover crops (groundcovers) in a study in the Bordeaux region of France, juice quality was enhanced through increased soluble solids and phenolic compounds while it deceased pH, titratable acidity (TA) and N (CARSOULLE, 1995). An often overlooked benefit of groundcovers is the economic return of reducing vineyard operations such as leaf pulling and fruit thinning. The majority of studies in France with permanent groundcovers have shown an overall increase in soluble solids over time as a result of reduced yields and increased fruit exposure (AGULHON, 1998; DAVID et al., 2001; MORLAT AND JACQUET, 2003). However, in other studies, the groundcovers had no effect on soluble solids in Portugal, Uruguay and Switzerland (AFONSO et al., 2003; NAZRALA, 2008). Wine and juice quality can usually be enhanced by reducing TA and pH and several studies have mirrored this when cover cropping was compared to bare soil. NAZRALA (2008) attributed this to reduction in reflected radiation (170 vs. 370 µmol $m^{-2}$ $s^{-1}$) and lower vine canopy temperature (26.7 vs. 30.8 °C). Soil temperature may also affect the absorption of potassium (K) into the plant and may influence juice acidity and pH. GUERRA AND STEENWERTH (2012) reported an agreement in the literature that groundcover treatments lowered leaf petiole nitrogen at bloom, reduced juice N concentration and extended fermentation time. To attain appropriate juice N levels in groundcover treatments supplemental N was added, however, after this addition wine ratings were highest amongst all treatments.

Another positive effect of permanent groundcovers is the general increase in anthocyanin and tannin levels, both in juice and wine (AGULHON, 1998; BOURDE et al., 1999; MORLAT AND JACQUET, 2003; NAZRALA, 2008; WHEELER et al., 2005). Grape clusters exposed to direct sunlight had greater total polyphenols, anthocyanins and flavanols than those growing in moderate sun exposure or shade (PRICE et al., 1995). More research isolating the effects of sunlight exposure and berry temperature may help explain the changes in grape nutrition and juice composition observed in vineyards where cover crops and groundcovers are used (SPAYD et al., 2002).

## GRAPEVINE WATER RELATIONS

Water is vital to all living organisms. The main driving force for vineyard water use is net radiation. Net radiation provides the energy to convert water in the liquid state (inside the leaf) to the vapor state (lost via stomata) outside the leaf (WILLIAMS AND AYARS, 2005). Throughout the world's wine grape growing regions, more and more acres are experiencing seasonal drought where soil and atmospheric water deficits, together with high temperatures, exert large constraints on yield and quality (CHAVES et al., 2007). The level of vineyard water use depends on a variety of factors. For example, a newly planted vineyard will have a lower water requirement than mature vines. In the first two years of growth, vines only use about 50 percent as much water as a mature vine of the same variety (CHAVES et al., 2007). Vine water use also varies throughout the season. Water use is low early in the season, from bud break until one month later. As the canopy begins to develop and leaf area increases, evaporative demand increases and vine water usage increases linearly until a full canopy is developed. After harvest, water usage begins to decrease as leaves begin to senesce and fall off the vine.

There is still controversy concerning the positive and negative effects of grapevine irrigation practices because if water is applied in excess it can reduce color and sugar content and produce acidity imbalances in the wine (BRAVDO et al., 1985; ESTEBAN et al., 2001; MATTHEWS et al., 1990). However, vines that are moderately water stressed have increased grape yield and fruit quality (FERREYRA et al., 2003; REYNOLDS AND NAYLOR, 1994; SANTOS et al., 2003). The key to improving grape quality in irrigated vineyards is to maintain a balance between vegetative and reproductive development, because an excess of shoot vigor may have negative impacts on fruit quality (MCCARTHY, 1997). A moderate water stress may reduce vine vigor and competition for carbohydrates by apical shoots, as well as promoting a shift in the partition of photoassimilates towards clusters and berries and secondary metabolites, thus resulting in increased fruit and wine quality (MATTHEWS AND ANDERSON, 1989).

## REMOTE SENSING TO PREDICT PLANT WATER CONTENT

Detection and monitoring of water stress is challenging because its onset is relatively slow compared to other natural disasters and each water stress event is distinct based on its duration, intensity and spatial extent (SWAIN, 2012; WILHITE AND GLANTZ, 1985). Water stress impacts both the survival and productivity of crops. Plants experience water stress when the transpiration demand exceeds the amount of moisture available in the root zone (KACIRA et al., 2002). Relative Water Content (RWC) is a biophysical variable that quantitatively expresses water volume per leaf and is expressed as the ratio of the amount of water present in the leaf at sampling time to the amount when the leaf is fully turgid and contains the maximum amount of water (SMART AND BINGHAM, 1974). Traditionally, water status in plants is determined either by measuring in-situ soil water status (such as soil water content or soil water potential) or by measuring in-situ physiological variables that characterize the water use and status in leaves (relative water content (RWC), leaf water potential (LWP), stomatal conductance ($g_l$) or photosynthetic rate). The problem with these methods is that they are time consuming, labor intensive and may not provide a good indication of the entire field or vineyard (JACKSON, 1982).

Infrared thermography in addition to other remote sensing techniques offers a non-destructive method of quantifying the water status of plants. There has been much research on various portions of the electromagnetic spectrum and their ability to quantify plant water content. The portions of the electromagnetic spectrum which have been the most studied are the near-infrared (NIR, 700-1300 nm) and the middle-infrared regions (MIR, 1300-2500) (CHEN et al., 2005; GAO, 1996; JACKSON et al., 2004; USTIN et al., 1998). Spectral reflectance of vegetation in the NIR region is determined by cell structure, leaf tissue characteristics, canopy architecture and the presence of two weak water absorption bands (970 and 1200nm). The reflectance in the MIR region of the electromagnetic spectrum is primarily controlled by the volume of water in leaf cells with the most absorption happening at 1450, 1950 and 2250 nm (CARTER, 1991; SIMS AND GAMON, 2003; TUCKER, 1980).

There have been many indices developed to help better understand plant water content using remote sensing techniques, for example, the Moisture Stress Index (MSI) (ROCK et al., 1986), Normalized Difference Infrared Index and the Normalized Difference Water Index (GAO, 1996; HARDISKY et al., 1983). The main problem with using such indices that make use of the NIR and MIR portions of the spectrum is that they have been shown to be less sensitive to RWC differences of 6% or less (RIGGS AND RUNNING, 1991), which are important when looking for early signs of drought/water stress. Another problem with using NIR and MIR bands is that they tend to saturate when the vegetation canopy closes or when the leaf area index (LAI) reaches 4 or greater (LILLESAETER, 1982). Relative water content in cotton has been shown to be weak and even statistically non-significant when it ranged from 92-100% (BOWMAN, 1989).

Another option making use of remote sensing is in the thermal infrared portion of the electromagnetic spectrum. Thermal sensors have the ability to sense vegetation temperature, which employs the principle that adequate moisture allows the plant to transpire at maximum rates, thus resulting in leaf temperatures lower than ambient air temperatures. Leaf temperatures are able to be lower than air temperatures because the amount of heat energy that is required for converting each mole of liquid water into water vapor is removed from the leaf as latent heat. This latent heat keeps the leaf cool (JONES et al., 2009). Therefore, leaf temperature begins to increase when soil moisture begins to diminish. Plants respond to this change by closing stomata to limit water movement out of the leaf via transpiration. As stomata close, the incident radiation on the leaf surface is primarily converted to sensible heat rather than latent heat which increases the leaf temperature and allows it to become warmer than the ambient air temperature (ANDERSON AND KUSTAS, 2008; FUCHS, 1990; MCVICAR AND JUPP, 1998). Use of thermal instruments to detect water stress can be used more quickly than other methods to identify changes in the MIR and NIR regions (JACKSON AND EZRA, 1985).

In the past few decades instruments have been developed to measure leaf and canopy temperatures of plants. In the late 1970's and 1980's small portable infrared thermometers (IRT's) were used to measure soil and plant temperatures using a small field of view (FOV) (FUCHS, 1990; IDSO et al., 1981; JACKSON et al., 1981; JACKSON et al., 1988; JONES, 1999; PAYERO AND IRMAK, 2006). The most commonly used index, which utilizes canopy temperature and other meteorological measurements such as ambient air temperature, relative humidity and irradiation (IDSO et al., 1981; JACKSON et al., 1981; JACKSON et al., 1988), is the Crop Water Stress Index (CWSI). For accurate results using the CWSI, upper and lower temperature baselines representing fully transpiring and non-transpiring leaves must be inserted into the equation (GUILIONI et al., 2008; LEINONEN et al., 2006). IDSO et al. (1981) developed an empirical method for quantifying stress by determining "non-water-stressed baselines" for crops. These baselines represent the lower temperature limit that a particular crop would attain if it were transpiring at its full potential which provides a simple method to normalize thermal images, both for incoming solar radiation (irradiance) and for measurement error within the sensor itself. For example, leaves sprayed with water or covered with petroleum jelly have proven to be convenient and accurate temperature indicators for transpiring and non-transpiring grape leaves (JONES, 2004; JONES et al., 2002; LEINONEN et al., 2006). MERON et al. (2003) and

MÖLLER et al. (2007) used a large "wet artificial reference surface" (WARS) as an indicator for airborne thermal imagery on 'Merlot' grapevines. This reference surface was constructed from a 5 cm thick slab of expanded polystyrene foam which was floated on a 40 cm x 30 cm x 12 cm plastic tray of water. The foam was coated with a double piece of 0.5 mm thick water absorbent non-woven polyester and viscose mixture cloth, overlaid on another 2 mm thick polyester non-woven water absorbent cloth. The edges of the cloth were placed in the water and acted as a wick, soaking up water to replace what was lost due to evaporation. In this particular experiment the upper baseline (dry reference) temperature was simply determined by adding 5 °C to the measured dry bulb temperature as suggested by IRMAK et al. (2000) and used by COHEN et al. (2005). It was concluded that the CWSI computed with air temperature +5 °C and the WARS for the dry and wet reference surfaces, respectively provided the most robust stress index (MÖLLER et al., 2007).

A serious limitation to using IRTs and water stress indices to determine water stress of a canopy is that the temperature data received by the thermal sensor are spatial averages of all materials within the field of view of the sensor. This would include all non-transpiring material such as brown trunks and canes, bare soil and blue sky, all of which will skew the canopy temperature average (SWAIN et al., 2012). Another potential issue with measuring grapevine canopy with a thermal sensor is that as the leaf area index (LAI) increases, the internal shading of leaves also increases. GRANT et al. (2006) and JONES et al. (2002) have reported significant temperature differences between sunlit and shaded leaves within a grape canopy.

Past studies have used thermal imaging approaches to estimate stomatal conductance of grapevine canopies (JONES et al., 2002), French beans and lupins (GRANT et al., 2006), stomatal resistance and stem water potential in olive trees (BEN-GAL et al., 2009) and LWP in cotton

(ALCHANATIS et al., 2010; COHEN et al., 2005). Stomatal conductance is considered to be a very sensitive and early indicator of plant water stress and has been predicted using the CWSI (MÖLLER et al., 2007), however, RWC is a more direct measure of water status because it compares the actual water content in a leaf against the content at full turgor. It has been argued that cell elasticity or turgor, which directly drives cell expansion and contraction, is the real indicator of water stress (JONES, 2007).

The research in this dissertation evaluates a broad spectrum of parameters relating to the impact that establishing groundcovers around newly planted ‘Edelweiss’ grapevines has on growth. The groundcovers were planted both in the alleyways as well as under-vine areas of the vineyard, which are conventionally controlled with burn-down herbicides. The following chapters outline the experimental design, methods of planting the groundcovers and the grapevines, and finally the results and conclusions from this four-year study.

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# CHAPTER 1

## Establishment of ‘Edelweiss’ Grapevines and Groundcover Treatments

## Materials and Methods

### Site Selection:

This research project was started in the spring of 2014 at Oak Creek Vineyards located near Raymond, Nebraska (40.947450° N -96.766140° W) within Lancaster County, Nebraska. Oak Creek Vineyards is a commercial vineyard that grows grapes on contract for James Arthur Vineyards and was gracious enough to allow the University of Nebraska Viticulture Program to conduct this research on their property.

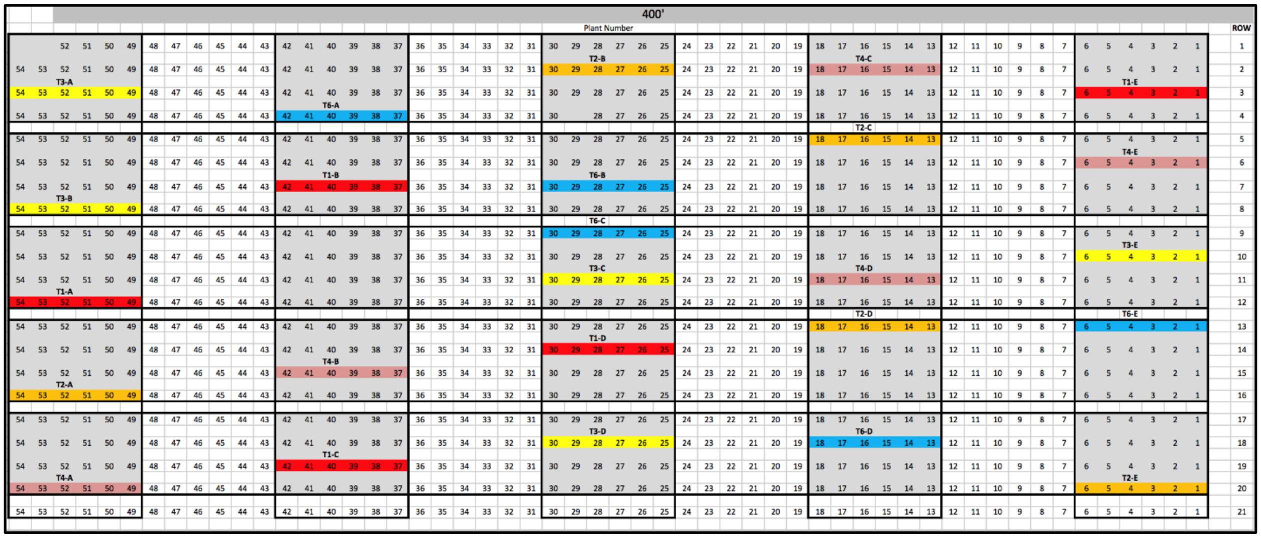
### Grapevines:

‘Edelweiss’ (Minnesota 78 x Ontario) grapevines were chosen for this experiment because of their popularity amongst grape growers, wineries, consumers in Nebraska and across the cool climate regions of the Midwest. This cultivar has a vigorous growth habit, which in some cases can become problematic for growers. Excessive growth can shade the fruiting zone and increase labor costs through extra leaf pulling, shoot thinning, and more intense pruning. Bare rooted ‘Edelweiss’ plants from Double A Vineyards Inc. (Fredonia, NY). were planted in May of 2014. Blue –X® (Double A Vineyards Inc. Fredonia, NY) grow tubes were placed around the young plants soon after planting and left in place until fall of the same year. Vines were trained to a 6 foot (1.83 m) high-wire trellis system with a spacing of 8 feet (2.44 m) between plants and 12 feet (3.66 m) between rows, with row orientation north to south.

## Experimental Design:

The experiment consisted of four groundcover treatments (Trt 1, Trt 2, Trt 3 and Trt 4) and a control treatment. The five treatments are explained in more detail in the following sections. A randomized complete block design was used with four blocks to account for the change in elevation and soil types across the vineyard (Figure 1.1). Change in elevation occurs from East (1287 feet above sea level) to West (1266 feet above sea level) across the vineyard. Soil types from East to West include Aksarben silty clay loam, Pawnee Clay Loam and Yutan silty clay loam, respectively (Web Soil Survey, 2018).

**Figure 1.1. Layout of experiment and treatments at Oak Creek Vineyards. Blocking occurs from top to bottom to account for change in slope and soil types. Each replicate consisted of four plants, with one buffer plant on either end of the replicate and four plants in the middle used for data collection. Trt 1 – Red, Trt 2 – Orange, Trt 3 – Yellow, Trt 4 – Pink, Control – Blue.**



400'

| Plant Number |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | ROW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 1 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | T2-B |  |  |  |  |  |  |  |  |  |  |  | T4-C |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 |
|  |  | T3-A |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | T1-E |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 3 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | T6-A |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 |  | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 4 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | T2-C |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 5 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | T4-E |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 6 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | T1-B |  |  |  |  |  |  |  |  |  |  |  | T6-B |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 7 |
|  |  | T3-B |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 8 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | T6-C |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 9 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | T3-E |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 10 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | T3-C |  |  |  |  |  |  |  |  |  |  |  | T4-D |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 11 |
|  |  | T1-A |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 12 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | T2-D |  |  |  |  |  |  |  |  |  |  |  | T6-E |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 13 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | T1-D |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 14 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | T4-B |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 15 |
|  |  | T2-A |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 16 |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 17 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | T3-D |  |  |  |  |  |  |  |  |  |  |  | T6-D |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 18 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  | T1-C |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 19 |
|  |  | T4-A |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | T2-E |  |  |  |  |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 20 |
| 54 | 53 | 52 | 51 | 50 | 49 | 48 | 47 | 46 | 45 | 44 | 43 | 42 | 41 | 40 | 39 | 38 | 37 | 36 | 35 | 34 | 33 | 32 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 21 |

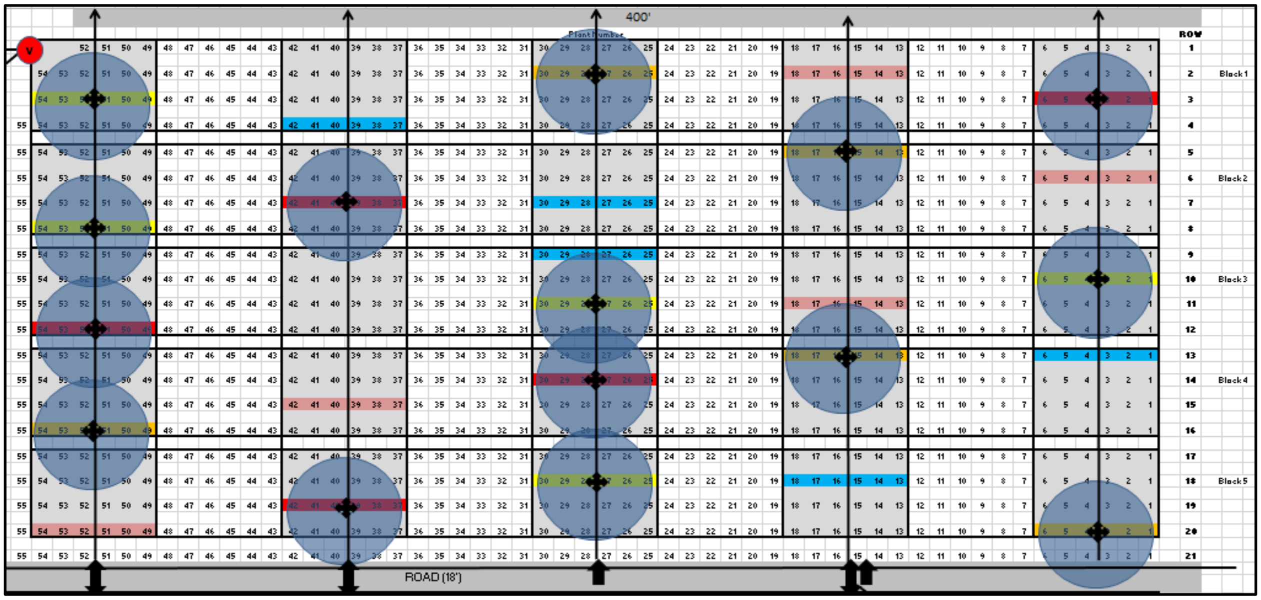
## Irrigation:

Precipitation can be highly inconsistent in late spring and summer in Nebraska so it was important to install a drip irrigation system to provide the young vines with supplemental water. In addition to providing the vines with adequate water in the first year it was also necessary to irrigate the groundcover plots to speed up establishment in order to outcompete resident weed populations. Additionally, with heavy spring rains it was important to establish the groundcovers as quickly as possible to reduce soil erosion.

An irrigation system for supplementing the grapevines with water was constructed using ½ inch drip line which was pulled into the ground and offset from the vine 18 inches (45.72 cm). The drip line was offset because the machine used to pull the pipe into the ground could not drive directly over the row. Grapevines were watered every three days consistently throughout the hot summer months.

The irrigation structure for the groundcover plots was constructed as an overhead irrigation system. Supply water lines ran west to east, perpendicular to the rows and were buried 12 inches below the surface. At each groundcover plot a ½ inch polyvinyl chloride (PVC) pipe was attached to the wood trellis post and a Rainbird® (Azusa, CA) rotary sprinkler head was attached to the top of the PVC at a height of 6 feet (Figure 1.2). This was done to increase the height of the sprinkler and increase spray distance. Each rotary sprinkler used a 4 gallon per minute (GPM) tip. Groundcover plots were watered for 30 minutes every other day just before dawn.

**Figure 1.2. Layout of irrigation system to water groundcover plots. The black vertical lines are the buried supply lines and the blue circles indicate the area that the rotary sprinkler head was watering. The control and natural vegetation plots did not receive supplementary irrigation. Trt 1 – Red, Trt 2 – Orange, Trt 3 – Yellow, Trt 4 – Pink, Control – Blue.**



## Groundcover Selection:

Groundcover seed was provided by Stock Seed Farms near Murdock, Nebraska. The selection of species in each groundcover mixture were chosen based upon a variety of factors including: rate of establishment, water usage, native range in the Midwest, ability to grow in compacted soils, low-growth habit and nitrogen fixing ability. Treatment 2, 3 and 4 are groundcover mixtures that are currently commercially available through Stock Seed Farms. Treatment 1 was a custom mixture put together specifically for this project. The groundcovers mixtures were as follows:

**Treatment 1 (Stock Seed Farms Roadside Mix®)**: Western Yarrow (*Achillea millefolium*), Birdsfoot Trefoil (*Lotus corniculatus*) and Dutch Clover (*Trifolium repens*).

**Treatment 2 (Custom Native Grass Mix)**: Hard Fescue (*Festuca brevipila*), Sheep's Fescue (*Festuca ovina*), Sideoats Grama (*Bouteloua curtipendula*), Texoca Buffalograss (*Buchloe dactyloides*) and Blue Grama (*Bouteloua gracilis*).

**Treatment 3 (Stock Seed Farms Orchard/Vineyard Mix®)**: Kentucky Bluegrass (*Poa pratensis*), White Clover (*Trifolium repens*), Red Fescue (*Festuca rubra*), Hard Fescue (*Festuca brevipila*), Chewing's Fescue (*Festuca rubra ssp. commutata*) and Perennial Ryegrass (*Lolium perenne*).

**Treatment 4 and 5**: Natural Vegetation in 2014 and was planted to Texoca Buffalograss (*Buchloe dactyloides*) in 2015.

**Control** – natural vegetation allowed to grow in the alleyways and a three foot swath beneath the vines was controlled as minimally as possible with herbicide.

**Figure 1.3. Images of the 4 groundcover treatments and the control in the spring of 2015, one year after they were planted. Treatment 1 – Image A, Treatment 2 – Image B, Treatment 3 - Image C, Treatment 4 – Image D and Control – Image E.**

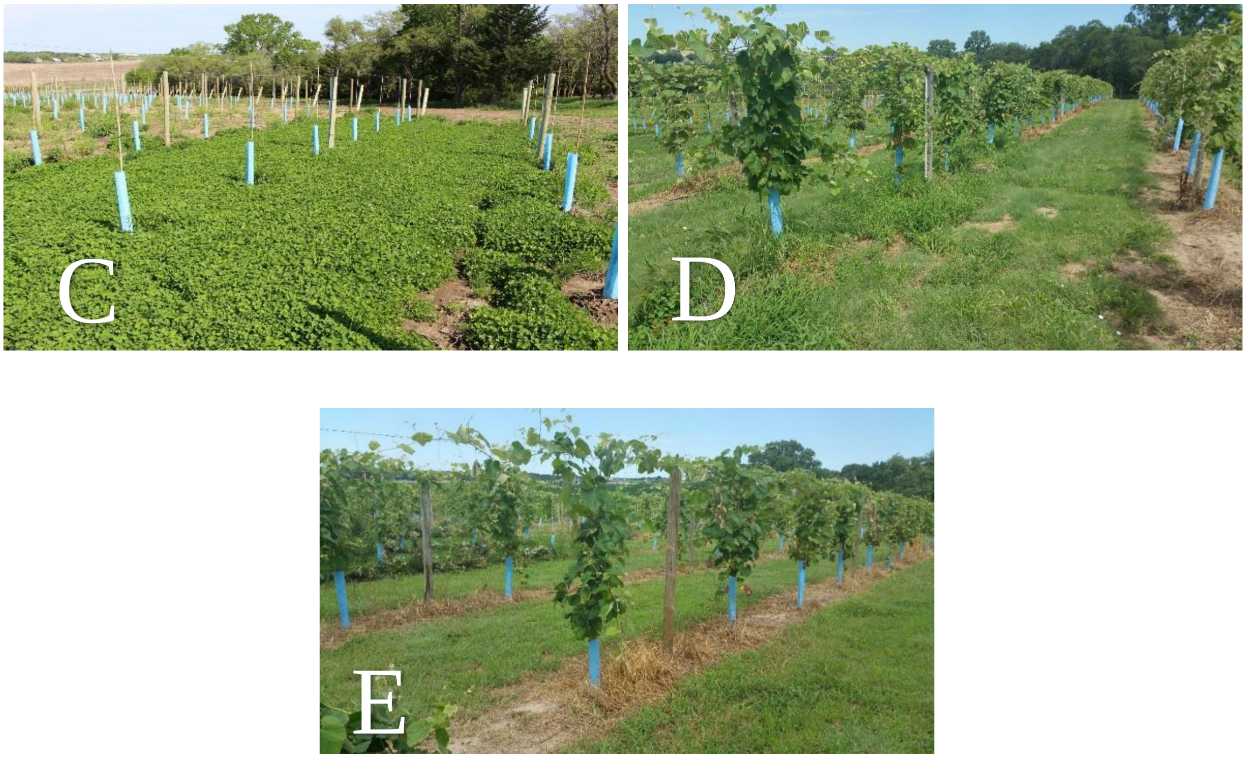


**Figure 1.4. Image of treatment 1 showing the plant species growing un-mowed under the vines. This was done to allow the groundcovers to flower.**

### Groundcover Establishment:

Groundcovers were drilled into the vineyard soil immediately after all of the vines were planted. The soil was prepared by using a soil conditioner attached to a skid loader. Once the ground was level and free of large clods, the grass seed mixtures were loaded into a native grass seed drill which was acquired from Pheasants Forever in Louisville, Nebraska. The drill was set to an 8-inch spacing between rows. The drill would not fit between plants, so in these areas the groundcovers were hand seeded and then incorporated into the soil using a hard rake. Once the seed had been drilled, plots were rolled and compacted using a Fimco® landscape roller to increase seed-soil contact and immediately watered. The seed was sown at a rate recommended by Stock Seed Farms based upon their commercial seeding rates for establishing new stands. Seeding rates and cost are as follows:

**Treatment 1**: 0.50 lbs/1000 $ft^2$ (21.8 lbs/acre) @ $8.75/lb.

**Treatment 2**: 0.75 lbs/1000 $ft^2$ (30.0 lbs/acre) @ $9.00/lb.

**Treatment 3**: 2.3 lbs/1000 $ft^2$ (100.0 lbs/acre) @ $2.15/lb.

**Treatment 4**: 3.0 lbs/1000 $ft^2$ (130.7 lbs/acre) @ $12.00/lb.

*Wholesale prices were for 2014. A retail customer would typically pay 15-20% more.

### Climatic Conditions from 2014-2017

Average monthly temperatures, monthly minimum and maximum temperatures and total monthly precipitation data from a weather station at the research vineyard are presented in Figure 1.5, 1.6 and 1.7, respectively. Overall, the 2016 growing season was warmer than 2014, 2015 and 2017 averaging 65.7 °F, whereas 2014, 2016 and 2017 averaged 62.6 °F, 63.9 °F and 63.9 °F, respectively. Precipitation was the highest in 2017 with 35 inches; 2014 and 2015 had very similar precipitation totals (32.2 and 32.9 inches) and 2016 had the lowest total precipitation with 25 inches. Heavy and fast rainfall events in May of 2015 caused fairly severe soil erosion in parts of the vineyard that had no groundcover.

**Figure 1.5. Average monthly temperature from March – October, 2014-2017. Data were recorded from a weather station located on the vineyard site 1 mile south of Raymond, Nebraska.**

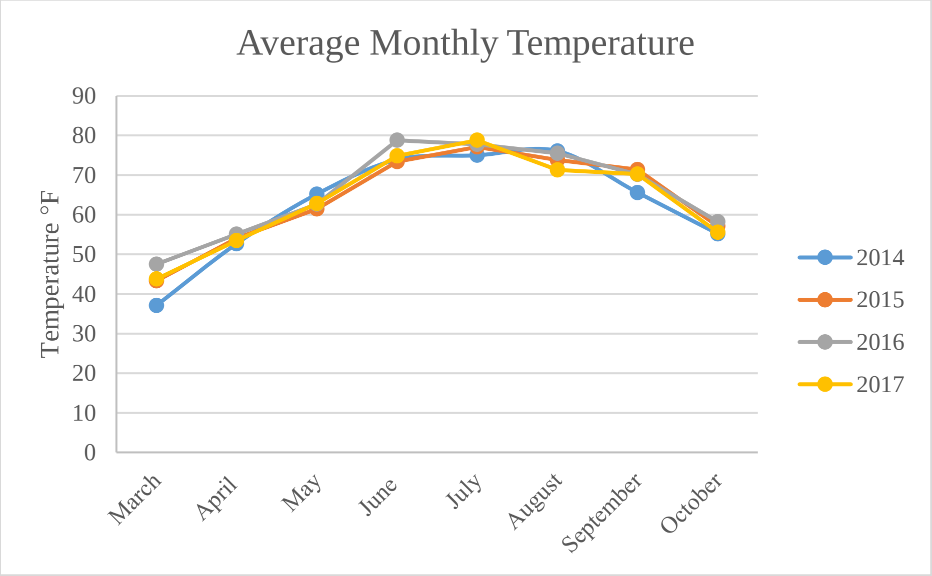


**Figure 1.6. Minimum and Maximum temperatures during the growing season from March to October, 2014-2017. Data were recorded from a weather station located on the vineyard site 1 mile south of Raymond, Nebraska.**

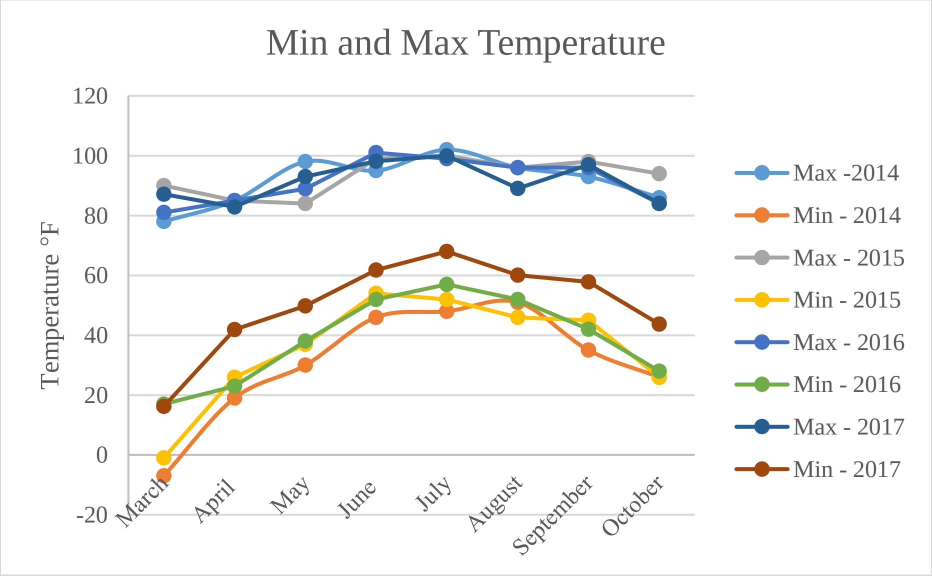
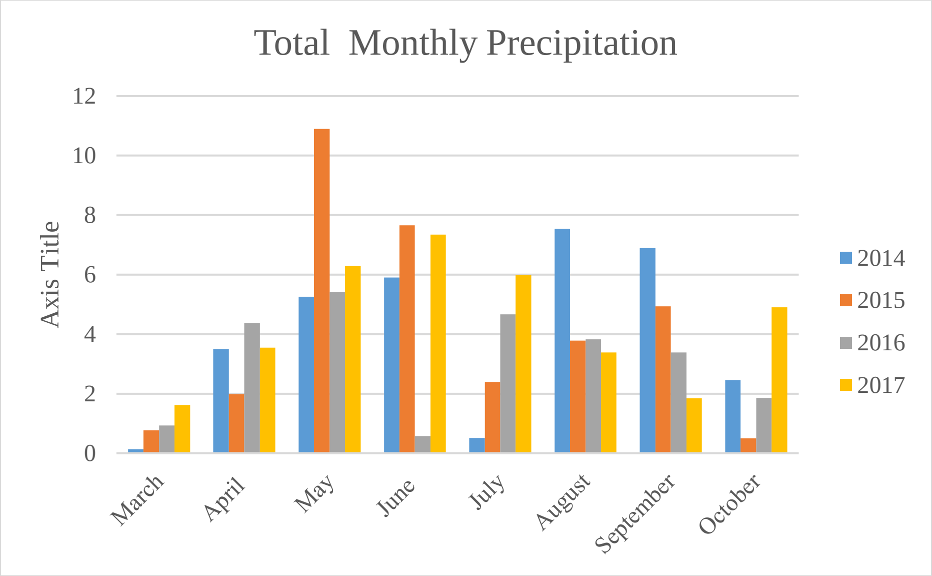


**Figure 1.7. Total monthly precipitation from March to October, 2014-2017. Data were recorded from a weather station located on the vineyard site 1 mile south of Raymond, Nebraska.**



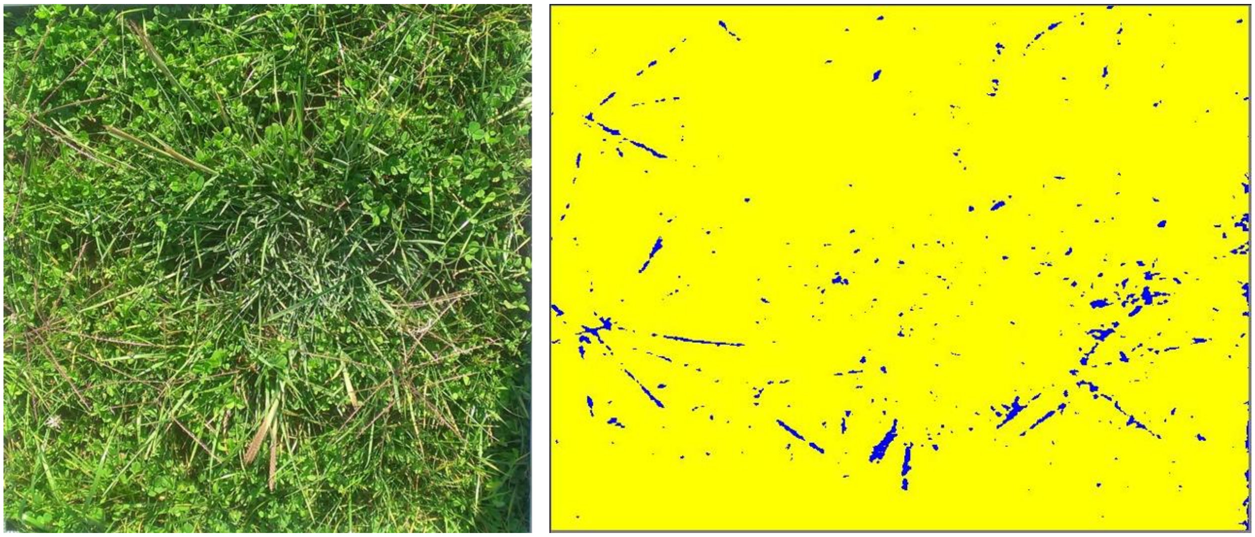
## Preliminary First Year Data Collection

### Rate of Groundcover Establishment

Data collection in year one was primarily focused on the rate of establishment by each groundcover treatment. The speed of establishment or how quickly the groundcover fills a given area is important because groundcovers reduce the resident weed seed population's ability to become established. Rate of establishment was assessed weekly beginning July 7, 2014 by placing a 24 x 24 inch PVC square on the ground in two predetermined places within each replication. The location for the square was randomly chosen on the first date but the same spot was used on the following dates. Location 1 was within the alleyway of the row and Location 2 was directly beneath the vines. A digital image was taken of the PVC square in each of the locations. The images were processed using Click to Crop® where all pixels outside of the PVC square were removed from the image. Images were then analyzed using the University of Nebraska's Center for Advanced Land Management Information Technologies (CALMIT)

VegFraction software which compared the percent of green vs. non-green material within each image (Figure 1.8). The rate at which the percentage of green vs. non-green material in each image increased over the growing season was used as an indicator for the rate of groundcover establishment.

**Figure 1.8. Cropped digital image of 24x24" square placed on the ground (left), both in the alleyway and under-row areas of the vineyard. The same image (right) after being processed with VegFraction software. All green material in the image is yellow and any non-green material is blue.**



### Shoot Length and Pruning Weights

Since this was the first year of vine growth, data collection involving the grapevines was minimal. As a preliminary gauge of how the groundcovers affected vine growth, shoot lengths were taken throughout the growing season and pruning weights were collected in the dormant season of year one. Shoot lengths were measured beginning on July 29th when the vines had just reached the top of the grow tubes. In each replication, the center two vines of four vines were used for data collection. The longest vine was measured from the top of the grow tube to the end of the vine and recorded. When a vine reached the six foot high wire, that specific date was recorded. This was done because the goal for plant growth in the first year of establishment is to reach the trellis wire and this date indicates how quickly that goal was reached or not reached. All of these measurements were done on the same two plants per replication on July 29, August 5, 12 and 19. The shoot lengths on each date from the two plants per replication were averaged together to obtain a single value for each replication.

Pruning weights were collected on March 15, 2015. Following standard first year protocol, all vines were cut back to the ground at the end of year one. Pruning weights collected in 2015 were actually the entire weight of the above ground portion of the vine. This total vine weight is an excellent indicator of vine growth in the first year of establishment. The two center vines from each replication were cut off just above ground level leaving one or two buds. The woody vine was then weighed using a digital balance. The two weights of each single plant experimental unit were recorded and averaged together to obtain a single value for each replication.

## Results and Discussion:

### Rate of Groundcover Establishment

The rate at which a groundcover is able to fill a given area and cover the bare ground is essential at limiting resident weed seed from becoming established. The quicker a groundcover is able to establish the less likely weeds will overtake the plot. Groundcover establishment in both the alleyways and the under-row portions of the vineyard were slightly different. In both areas the groundcovers had similar rate of fill (slopes were similar), however, percent of cover of each treatment was different between the two areas. In the alleyway, Trt 1 and Trt 3 were not different from one another, in that, they had similar percent cover throughout all collection dates (Figure 1.9). Percent cover for these two treatments started at 20% and increased linearly to an end point of around 90% cover. Trt 2 was different from Trt 1 and Trt 3 in that it consistently had a lower percent cover throughout all dates. This was expected as native prairie grass species are typically slower growing and spread more gradually. The herbicide control and the natural vegetation treatments were nearly identical in their percent cover and rate of establishment. Interestingly, by the end of the first year these two treatments only covered around 50% of the ground, making the soil highly susceptible to erosion.

Groundcover establishment under the vine-row showed differences compared to establishment in the alleyways (Figure 1.10). The control and natural vegetation treatments again had similar rates of establishment throughout the first year with slight differences in the percent cover across all dates. The three groundcover treatments also showed similar rates of establishment. Trt 2 (native grass mix) showed a faster rate of establishment and final percent groundcover in the under-row areas of the vineyard. This can most likely be attributed to the difference in seeding practices between the two areas. In the alleyways, the seed was drilled on 8” centers, whereas, under the rows the seed was hand seeded at heavier rates. This difference in seeding rates is clearly seen in the two plots (Figure 1.9 and 1.10). All groundcover treatments ended up with over 90% cover by the end of the year.

**Figure 1.9. Rate of groundcover establishment in the vineyard alleyways in 2014. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Natural Vegetation; Control = weeds controlled by herbicide under-row.**

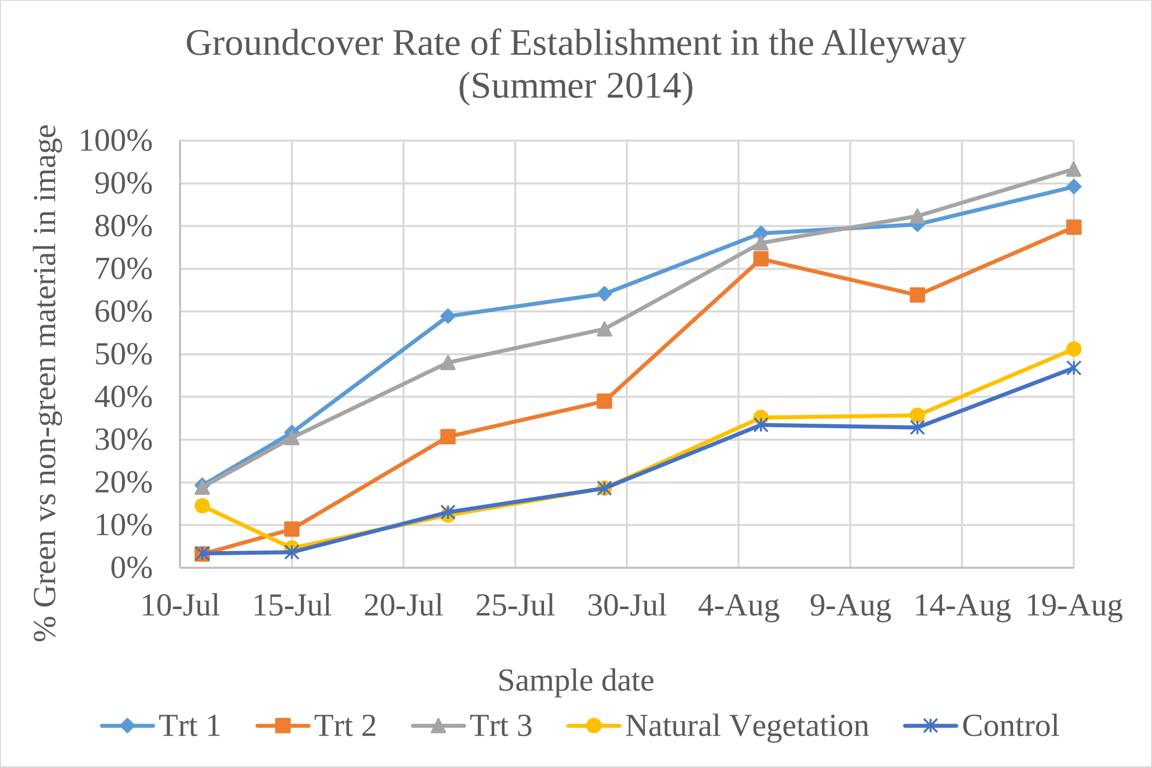
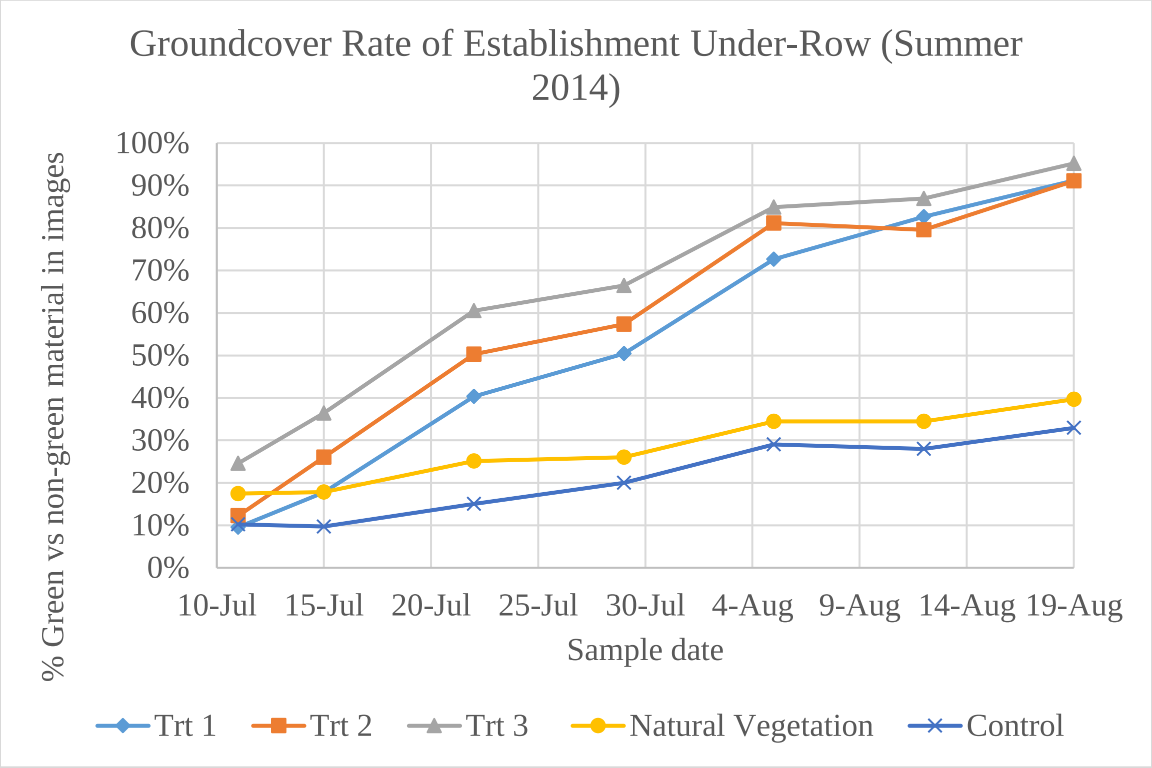


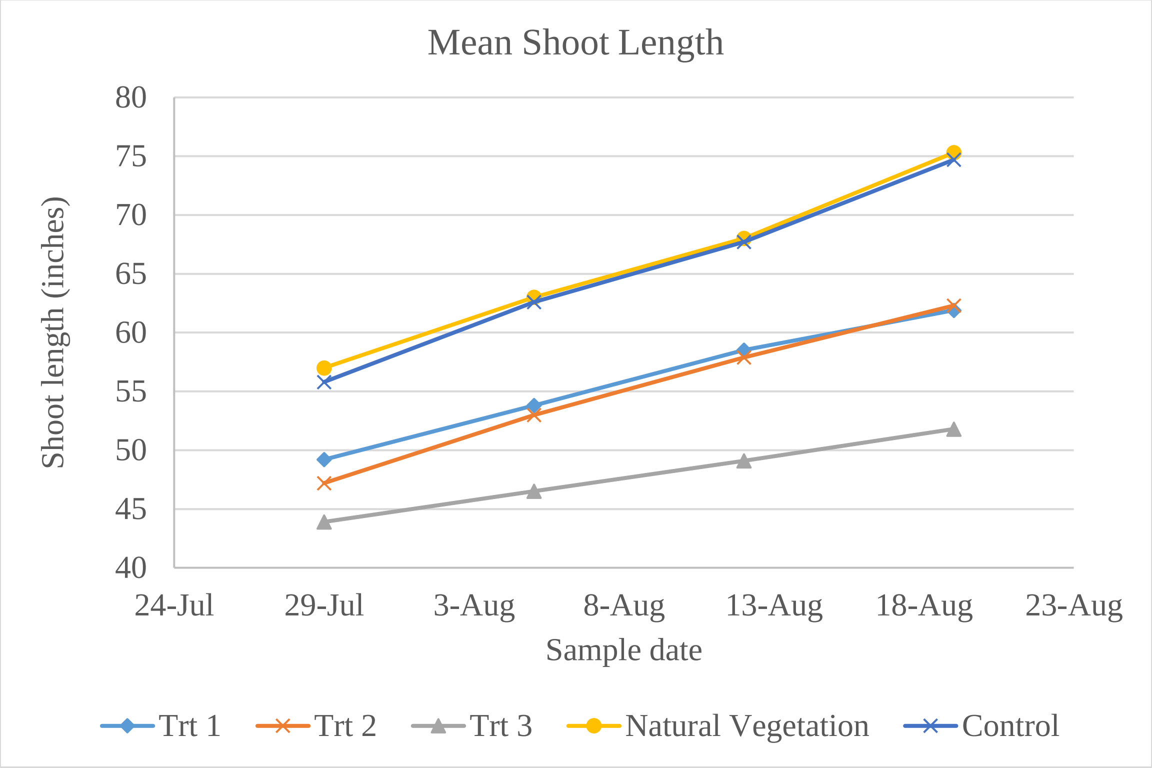
**Figure 1.10. Rate of groundcover establishment under the vine-row in 2014. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Natural Vegetation; Control = weeds controlled by herbicide under-row.**



## Shoot Length

Shoot length is a direct indicator of vine growth and can be used to gauge the amount of competition between the vines and groundcovers for water, nutrients and other factors. The natural vegetation and herbicide sprayed control had nearly identical vine shoot lengths throughout all measurement dates. Trt 1 and Trt 2 also had very similar shoot lengths throughout all measurement dates, with an ending length of 62 inches. Finally, Trt 3 showed the slowest vine growth in the first year. It had the slowest growth rate and did not reach the trellis wire, which was at 60 inches (Figure 1.11). The goal for first year growth is to at least reach the wire and hopefully have enough length to lay cordons onto the wire. It appears that all groundcover treatments had a negative impact on vine growth in the first year. Because none of the vines had much more growth beyond the height of the wire, the vines were cut back to just a few buds above the ground in the winter of 2015.

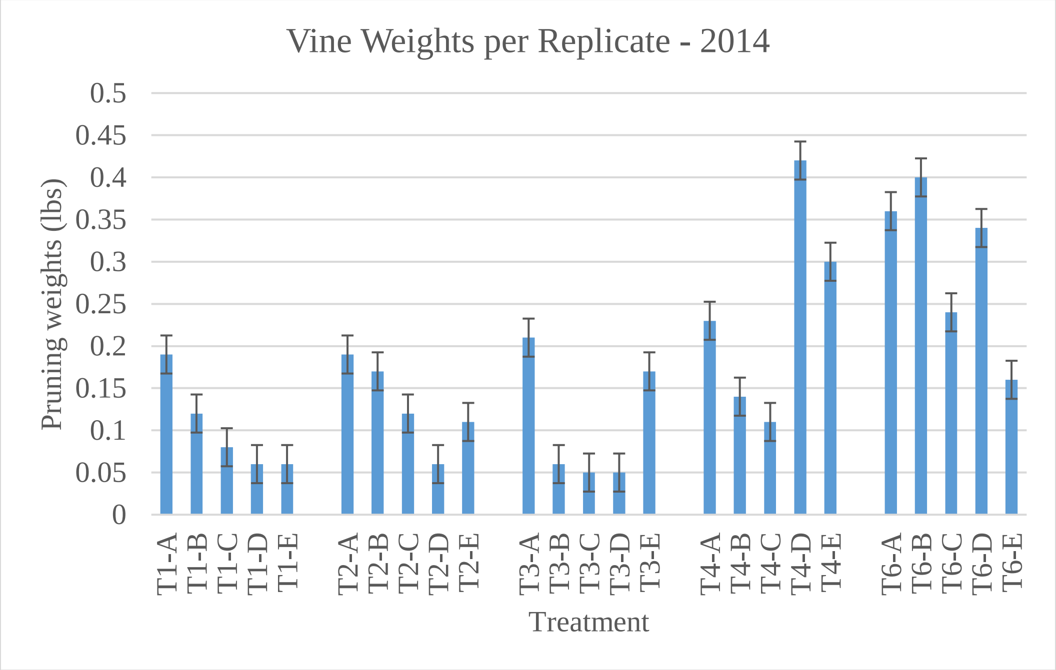
**Figure 1.11. Average shoot length measured from the top of the grow tube to the end of the longest shoot in 2014. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Natural Vegetation; Control = weeds controlled by herbicide under-row.**



## Pruning Weights/Total Vine Weight

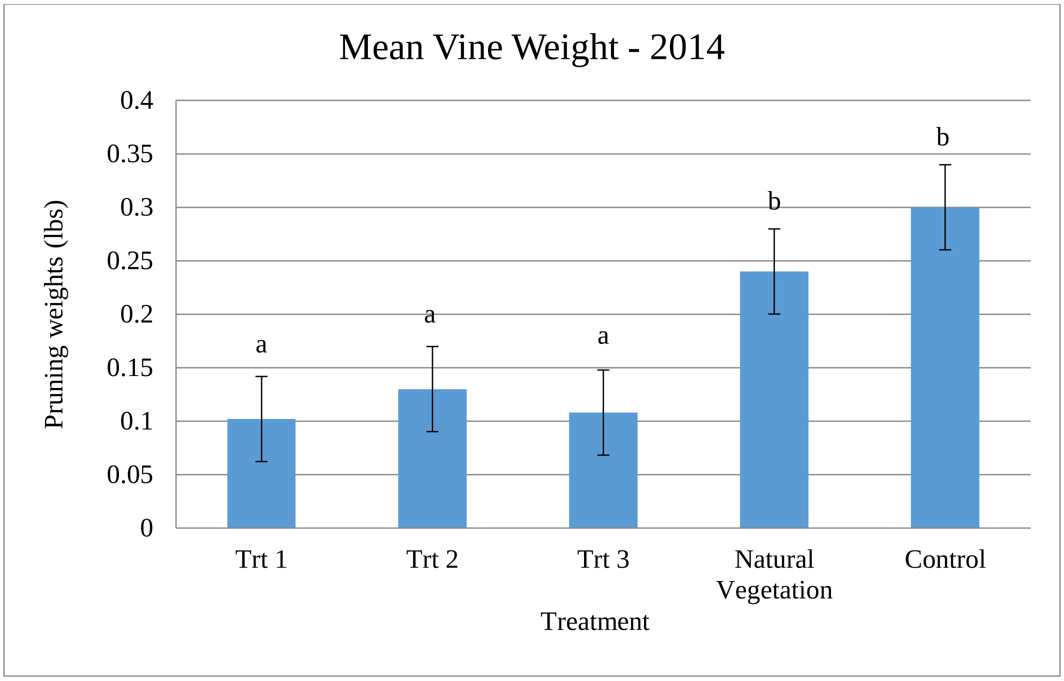
Pruning weights were collected in winter, 2015. Following first year standard protocol, the entire vine was cut back, leaving just a few buds on a short portion of the trunk above the ground. Pruning weights represent the entire weight of above ground growth put on by the vine in the first growing year (2014). There were clear differences between vines growing with groundcovers, natural vegetation and control treatments (Figure 1.13). As expected, the vines with the herbicide sprayed under-vine area (control) had the most amount of growth in the first year and had the highest pruning weights of 0.3 lbs/vine.  Natural vegetation affected growth of the vines slightly and led to reduced pruning weights by 0.06 lbs/vine compared to the control. The three groundcover treatments were not statistically significantly different from one another, however, they significantly reduced pruning weights when compared to the herbicide sprayed control.  Groundcovers reduced vine weight by up to 67% (Figure 1.12 and 1.13).  This reduction in vine growth in the first year would not be a positive result of using groundcovers.  The goal for newly planted vines in the first year of establishment is to put on as much growth as possible and reach the trellis wire and beyond.  If insufficient growth occurs in the first year, vines are typically cut back to the ground and allowed to regrow from a few buds in the following year. This technique allows energy reserves in the root system to push new growth to a greater extent in the second year.

**Figure 1.12. Average pruning weight of two vines/replicate in all treatments. Data represent growth from the first year of growth (2014). Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Natural Vegetation; Control = weeds controlled by herbicide under-row.**



*Error bars represent mean ± SE.

**Figure 1.13. Pruning weight average of all replications for each treatment. Data represent growth from the first year of growth (2014). Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Natural Vegetation; Control = weeds controlled by herbicide under-row.**



*Columns with same letters are not significantly different at $p \leq 0.05$. Error bars represent mean ± SE.

## Conclusions

1. The use of supplementary irrigation increased the rate of groundcover establishment and limited the infestation of native weed species. It is recommended that growers should irrigate newly planted groundcovers.
2. All of the planted groundcover treatments became established and filled the ground area much faster than the natural vegetation and control treatments. In 2015, heavy rainfall events created severe soil erosion in this new vineyard. In the control, treatments that had little vegetation covering the ground, the water eroded soil so badly that there were

12 inch deep gullies running through the vineyard. As a result, remedial measures had to be taken, where the vineyard manager was forced to haul in soil to fill in the gullies. In the areas where the groundcovers were planted, little-to-no soil erosion was noticed.

3. Vine growth was affected by the groundcovers in 2014. The control and natural vegetation treatments had much higher shoot lengths and vine weights. This preliminary data indicates that planting groundcovers simultaneously with grapes is detrimental to the growth of young vines. This effect is probably magnified by the fact that the groundcovers were planted in the vine row, an area of the vineyard that is typically kept weed-free through the use of herbicides. Further investigation is needed comparing the effects of groundcovers planted in the first or second year of vineyard establishment.

# CHAPTER 2

## Leaf Water Potential and Vine Growth in 2015, 2016 and 2017

### Introduction

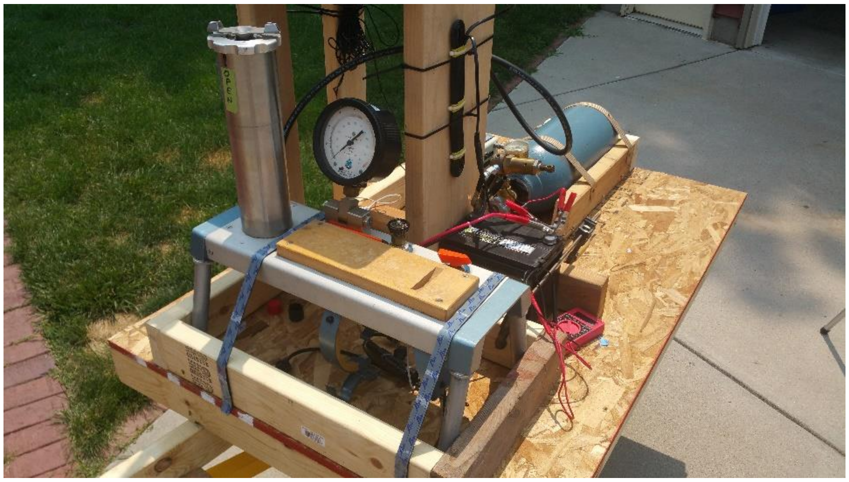
In years 2015, 2016 and 2017 the bulk of the data were collected and used to accomplish the major objectives of this project. This included Midday Leaf Water Potential ($\Psi_{md}$), pruning weights, soil samples, petiole samples (2017) and harvest parameters including: total yield, clusters per plant, cluster weight, berry weight, pH, TA and °Brix. The main objective of these sections is to determine how the groundcovers impacted the grapevine growth parameters listed above.

### Materials and Methods

### Leaf Water Potential

Leaf water potential measurements were taken on June 30, 2015. On this date the vines had reached full canopy and the dry summer season had begun. $\Psi_{md}$ was measured using a pressure chamber (model 2005HGPL, Soil Moisture Equipment Corp., Santa Barbara, CA). In the first year, the center two vines of the 6 vine experimental unit in each replication were chosen. A single mature, fully expanded leaf on each plant was used for $\Psi_{md}$. The leaves were exposed to direct solar radiation and were located on the East side of the canopy. Midday measurements occurred as close to solar noon as possible (12:30 – 2:30 pm, Central Daylight Time) when the vines were at a peak water stress level. Leaf blades were covered with a plastic bag, quickly sealed and then petioles cut within 1 to 2 seconds. The time from leaf excision to the pressure chamber measurement was generally less than 10 seconds. Measurements were repeated every week throughout the growing season and were only collected on days when skies were clear to mostly clear and no precipitation events had occurred that day. In 2016 and 2017, the same methods were used with one exception; the center four plants were used for data collection in order get a better degree of the $\Psi_{md}$ in the whole replicate and to increase statistical power, rather than just two plants which was done in 2014 and 2015.

**Figure 2.1. Specially constructed data collection cart. Data from multiple devices was collected simultaneously when Midday Leaf Water Potential ($\Psi_{md}$) was measured. Devices included a pressure bomb, weather station (air temp and relative humidity), pyranometer (irradiance) and Anemometer (wind speed).**



## Pruning Weights

Pruning weights were measured on March 17, 2015, February 17, 2016 and February 16, 2017. Vines were pruned leaving 4 to 5 buds on each cane. Prunings were collected and weighed from the four center plants within each replication.

## Bud Break

Bud counts were taken every three days and began on April 7, 2016 and April 8, 2017 and concluded April 22, 2016 and April 29, 2017, respectively. Bud break was determined as stage four of the modified Eichhorn-Lorenz (E-L) scale of grapevine development (COOMBE, 1995). Stage four indicates that the bud scales have expanded to the point where the first leaf tissue is visible. Buds on one preselected cane per plant within each four plant replication were counted and recorded. Bud break counts were taken on each preselected cane until bud break had reached 60% (three out of five buds open). Complete bud break was considered when 60% of the buds had reached stage four. The Julian date (beginning January 1) was recorded when the cane had reached 60% bud break.

## Harvest

Harvest occurred on August 10, 2016 and August 15, 2017. The four center vines were again chosen for data collection where all of the fruit from each plant was harvested individually. Total number of clusters were counted and the weight was recorded. Using these data, average cluster weight was calculated. Once the fruit from each plant was weighed, 100 berry samples were taken from each plant and placed into a plastic freezer bag. These samples were taken back to the lab where they were frozen and later analyzed for pH, TA and °Brix.

Berry analysis was conducted on September 15, 2016 and September 19, 2017 to measure pH, TA and °Brix. Berries were removed from the freezer the day before testing and placed in a cooler (40 °F) to thaw. On the day of testing, the berries were removed from the cooler and warmed to room temperature. Berry samples were then crushed within the plastic freezer bag and the juice was extracted by cutting a small hole in the bag, allowing the clear juice to run out into a 100 mL beaker (LOSEKE et al., 2015). The extracted juice was then poured into test tubes to conduct the analyses. Juice pH was measured with a Hanna pH/ORP meter model HI 2211 (Hanna Instruments, Woonsocket, RI). Soluble solids (°Brix) content was measured using an Atago PR-101 digital refractometer (Atago U.S.A, Bellevue, WA). TA was determined with the use of a Hanna HI 900 (Hanna Instruments, Woonsocket, RI) automated titration system.

## Soil Samples

Soil samples were collected in the spring of 2015, 2016 and 2017 before the grapevines had broken dormancy. Samples were taken at a depth of 12 inches from each replication in the vineyard. Each sample consisted of a composite of 6 subsamples, two taken from within the alleyway on either side of the vine row and two taken from within the vine row. All samples were taken randomly within each replication. Samples were taken to AgSource laboratories (Lincoln, NE) where they were analyzed for pH, EC, organic matter and a variety of nutrients.

## Statistical Analyses

All data ($\Psi_{md}$, harvest, pruning weights, soil samples and bud break) were treated as a Randomized Complete Block Design with a Two-Way ANOVA using the GLIMMIX procedure. Main and simple effects were compared at $P \leq 0.05$, when appropriate. A repeated measure covariance structure was also fit to the residual of each model for $\Psi_{md}$ to account for the dependencies imposed by sampling over time. In 2015 and 2016 the ANTE(1) covariance structure was used and in 2017 the SP(POW) structure was used to accommodate unequally spaced collection dates in the three years. Data were analyzed using SAS/STAT® Version 9.2 (SAS Institute, Cary, NC).

## Results and Discussion

## Leaf Water Potential

In many growing regions across the world, vines are grown for wine production without the supplementation of irrigation. Under dry conditions when a relatively small amount of water supplements the vines, a large increase in grape production can occur (DOS SANTOS et al., 2003; FERREYRA et al., 2003; MATTHEWS AND ANDERSON, 1989; REYNOLDS AND NAYLOR, 1994).

However, it is generally thought that wine quality is diminished with increased irrigation and berry size. Due to this, a full irrigation regime is seldom applied to wine grape vineyards (GIRONA et al., 2006). The most common irrigation practice is to apply only enough water to keep the vines from becoming moderately to seriously water stressed. Maintaining a mild water stress during the final stage of berry development increases the proportion of skin to grape juice, thus improving wine color and flavor (WILLIAMS et al., 1994).

LWP thresholds have been defined for *vinifera* grapevines by WILLIAMS AND ARAUJO (2002); CHONÉ et al. (2001) and GRIMES AND WILLIAMS (1990). Generally speaking, in California it is advised that irrigation should be initiated when $\Psi_{md}$ levels reach -10 bars, where -15 to -16 bars is the lowest $\Psi_{md}$ value achieved under dry conditions. There have not been any $\Psi_{md}$ thresholds established for many of the grape cultivars grown in the Midwest United States, including 'Edelweiss' which was the grape used in this project. In order to design an irrigation regime to maintain a slight water deficit one must first have a baseline for no water stress and complete water stress. A separate greenhouse project was conducted to determine these baselines and is outlined in detail in the following chapter.

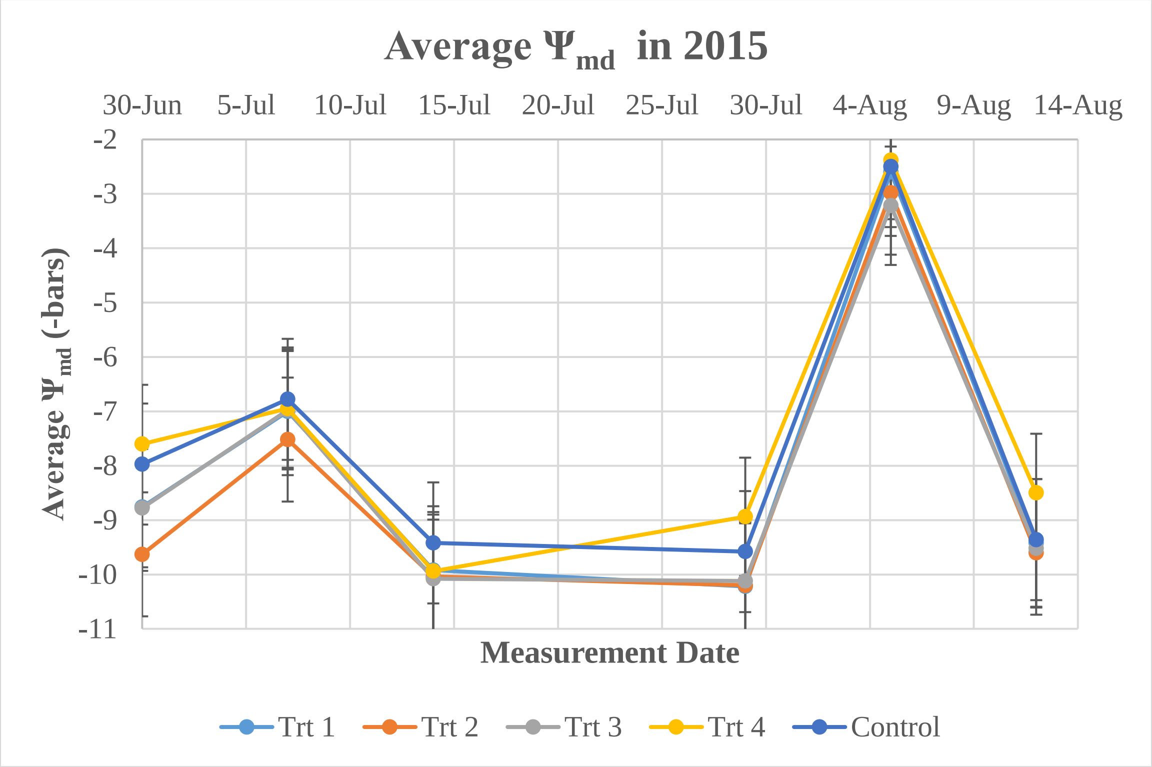
Midday leaf water potential was measured in 2015, 2016 and 2017 to observe the effects different groundcover treatments had on the water status of neighboring 'Edelweiss' grapevines. Because environmental conditions varied greatly between years, comparisons between treatments across the three years was not possible. Therefore, the treatments were only compared within each individual year.

### 2015 – Midday Leaf Water Potential

In 2015 there was not a treatment*date interaction so the data were averaged across all dates for each individual treatment. The only significant difference that was observed when data from all dates was averaged was between Trt 2 and Trt 4 (p=0.0235), where Trt 2 had a lower $\Psi_{md}$. There was only one instance where a treatment was statistically significantly different from the control in 2015 which was on July 29, where Trt 1 had a higher $\Psi_{md}$ of 1.79 bars (p=0.0193). Other than that, there were no significant differences between any of the treatments and the control (Appendix H), indicating that in 2015 the groundcovers did not reduce the availability of water to their neighboring grapevines, thus causing higher water stress.

The four groundcover treatments and the control showed a similar pattern of change in $\Psi_{md}$ across all dates in 2015, however, there were clear significant difference in $\Psi_{md}$ between the dates (Figure 2.2). When data from all the treatments is averaged from each collection date drastic differences in $\Psi_{md}$ between dates can be seen, with high and low $\Psi_{md}$ throughout the summer. Most apparent was the change on August 15 when $\Psi_{md}$ was only -2.7 bars. $\Psi_{md}$ values on all other dates ranged from -7 to -9.8 bars. This can be explained by the rainfall event that happened the day before data collection and the cooler temperatures (between 75 °F and 80 °F) on the day of collection. On this date, the grapevines exhibited no water stress and the stomata would have all been fully open and transpiration was occurring at full capacity. The two dates that exhibited the lowest water potential in 2015 were July 14 and 29 where vines had an average water potential of -9.8 bars. If these grapes were managed using California $\Psi_{md}$ thresholds, irrigation would not even have been used in 2015.

**Figure 2.2. Plot of Midday Leaf Water Potential ($\Psi_{md}$) collected weekly from 'Edelweiss' grapevines from June 30 to August 12, 2015. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**

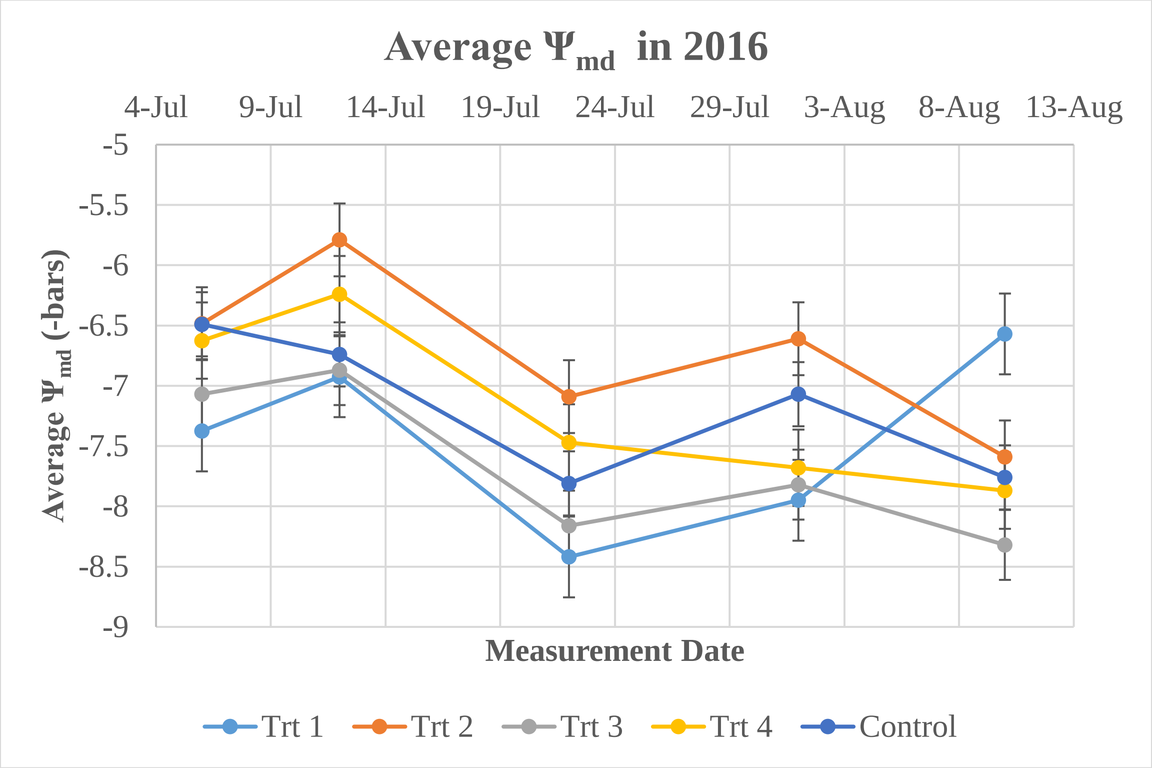


## 2016 – Midday Leaf Water Potential

Similar to what was observed in 2015 the Treatment*Date interaction was not significant so again the data were combined and averaged within each collection date. Generally speaking the treatments followed the same pattern across all collection dates, but in a few cases the treatment line crossed indicating a possible interaction (Figure 2.3). For example, on August 1st, Trt 1 is at the bottom of the $\Psi_{md}$ values but then jumps to the top on August 10th. This is a sign that there could be differences between treatments within certain dates but not others, which is another sign of interaction. The simple effects show smaller significant differences among treatments as what was seen in 2015 (Appendix H).

When the data from each treatment are averaged across all dates a very small difference is observed in $\Psi_{md}$, with the lowest being Trt 3 (-7.6 bars) and the highest being Trt 2 (-6.7 bars). This is only a difference of 1.1 bars and would typically be insignificant to the grape grower, especially since these vines do not appear to be water stressed at these $\Psi_{md}$ levels. The statistics indicate that there are only two instances where treatments are significantly different from one another. Trt 2 had a significantly higher $\Psi_{md}$ compared to Trt 1 (p=0.0297) and Trt 3 (p=0.0098). However, none of the treatments were significantly different from the control in any of the dates (Appendix H).

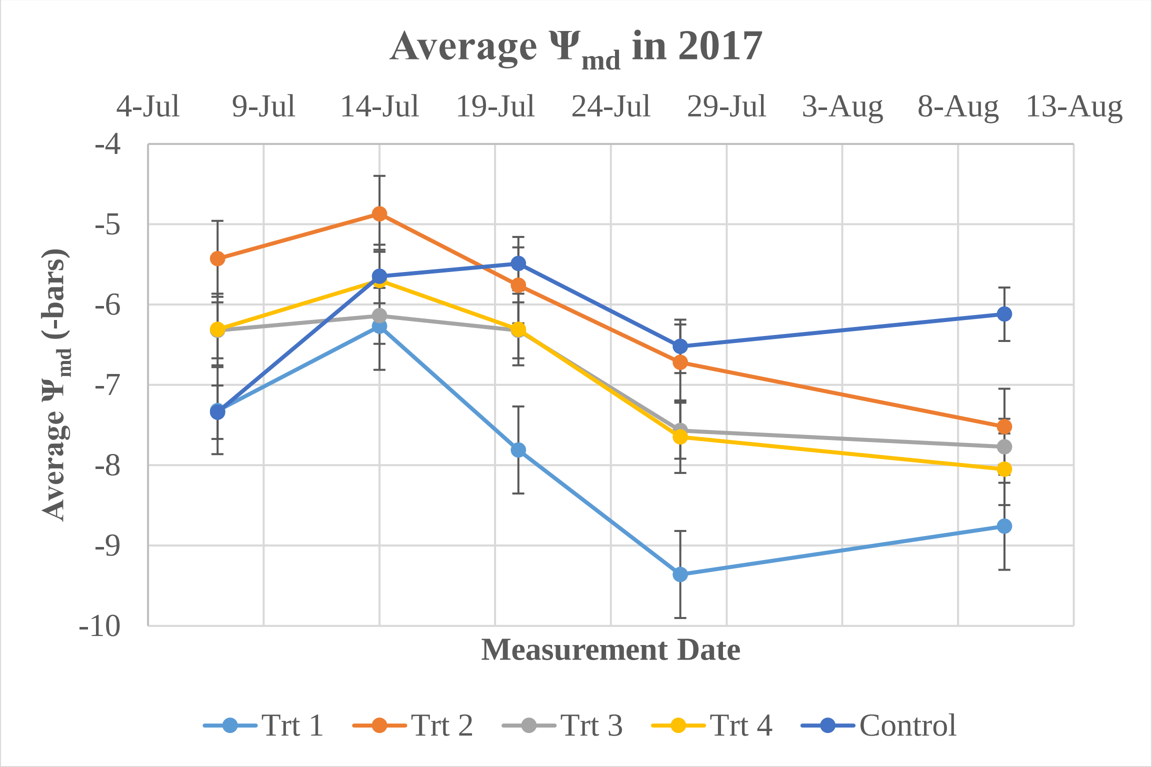
**Figure 2.3. Plot of Midday Leaf Water Potential ($\Psi_{md}$) collected weekly from 'Edelweiss' grapevines from July 06 to August 10, 2016. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**



**2017**

In 2017, it appeared that there was a very strong interaction between the treatments and the dates, so it's most appropriate to look only at the simple effects and not the main effects, unlike in 2015 and 2016. Generally speaking most of the treatments showed more negative $\Psi_{md}$ than the control, especially as the season progressed. Trt 1 had the lowest $\Psi_{md}$ throughout the entire season. By merely looking at the plot (Figure 2.4) it is clear that from July 14 to July 27 there was a dry period in the vineyard. The $\Psi_{md}$ during these weeks of all treatments dropped. Interestingly, the control showed a less sharp drop in $\Psi_{md}$ during this dry period than the vines growing alongside groundcovers. The treatment comparisons throughout the collection dates are shown in Appendix I. As the season progressed, all of the groundcover treatments were significantly different from the control. At this point the grapevines had been growing within their groundcovers for 3 years and began to exhibit the negative effects of water competition. Although, if the goal is to keep the vines moderately water stressed and control vine vigor than groundcover treatments were beneficial. It will be important to examine harvest and yield results before making these conclusions.

**Figure 2.4. Plot of Midday Leaf Water Potential ($\Psi_{md}$) collected weekly from 'Edelweiss' grapevines from July 07 to August 10, 2017. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**

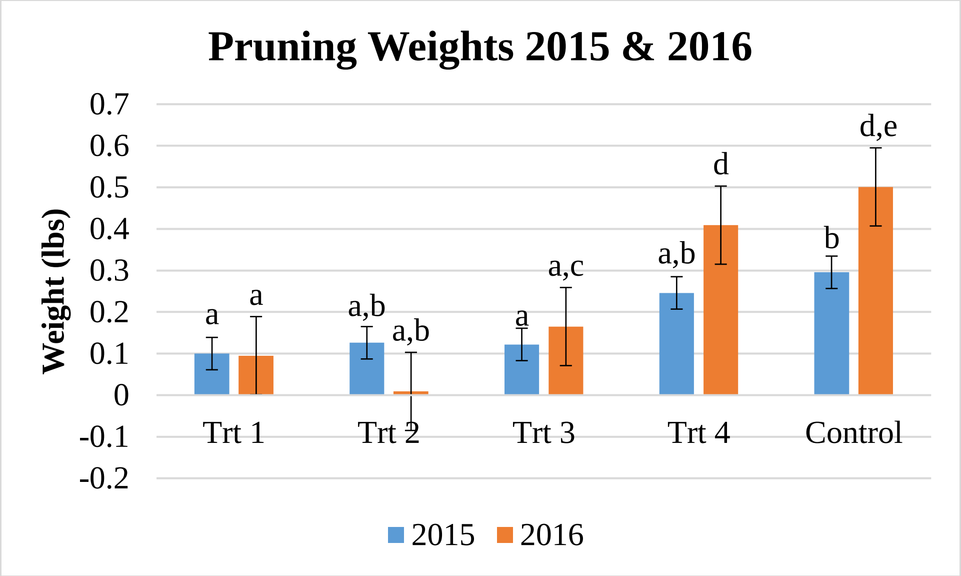


## Pruning Weights 2015 and 2016

Pruning weights are a direct measure of the vegetative growth in the year prior to pruning. Pruning weight measurements are used in conjunction with yield measurements to calculate yield-to-pruning weight ratios (DOBROWSKI et al., 2003). These indices are representations of the vegetative and reproductive balance and can be used as an indirect measurement of fruit quality (SMART AND ROBINSON, 1991). Pruning weights were collected in the winter of 2016 and 2017, which means the growing season of 2015 and 2016 were the years of interest, respectively.

The second growing season was 2015 and the third was in 2016, which was the first year the vines produced fruit and were harvested. It would be expected that the vegetative growth would increase dramatically across all treatments from the second to third year of growth. Interestingly, this was not the case in any of the groundcover treatments. The control was the only treatment that showed significantly greater pruning weights from 2015 to 2016 (p=0.0391). In Trt 2, the pruning weights actually decreased from 2015 to 2016 (0.126 lbs down to 0.095 lbs) (Figure 2.5 and 2.6). This is an indication that the groundcover treatments are restricting the growth of the grapevines on some level, possibly water or nutrient competition or even an allelopathic characteristic by some of the groundcover species.

**Figure 2.5. Chart of pruning weights in 2015 and 2016. Data were collected in winter of 2016 and 2017, respectively. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**



*Columns in the same year with same letters are not significantly different at $p \leq 0.05$.

In 2015, the vines that were grown with a chemically controlled area beneath (control) had the highest pruning weights when compared to the four groundcover treatments (Figure 2.5).

The control vines had an average of 0.30 lbs per vine and the four groundcover treatments ranged from 0.1 lbs to 0.25 lbs per vine, with the greatest being Trt 4 and the lowest being Trt 1, however there were not significant differences among any of the treatments. Trt 1 and Trt 3 both had significantly lower pruning weights compared to the control.

In 2016, a similar pattern emerged where the control had 193% higher pruning weights than the vines growing under the native grass groundcover treatment (Trt 2). The other three-groundcover treatments had reduced pruning weights ranging from 20% to 136%. The control had an average of 0.5 lbs of growth per plant. Treatment 2 (native grass) had the lowest pruning weights at 0.009 lbs per plant. All of the treatments with the exception of Trt 4 were significantly different than the chemically maintained control.

These results clearly show the detrimental effects planting groundcovers has on the growth of newly planted vines and coincide with past studies that have found that increasing soil coverage by a perennial grass groundcover reduces vine vigor (GIESE et al., 2010; HATCH et al., 2011; MORLAT AND JACQUET, 2003).

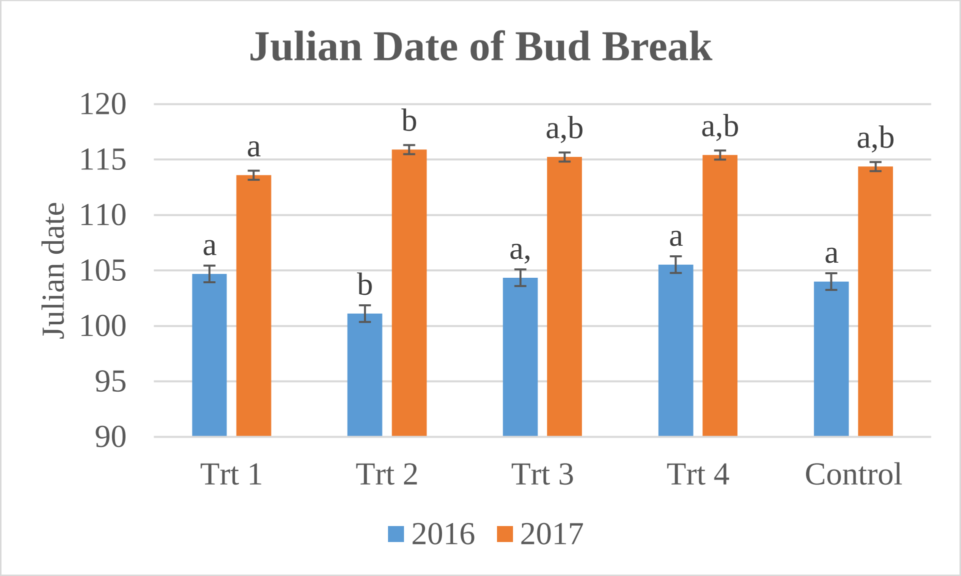
**Figure 2.6. Images showing vines growing within the Treatment 2 groundcover (native grass mixture) in the summer and winter of 2016. Vines had significantly less growth under this treatment when compared to all other treatments.**

## Bud Break

Winegrape production can be compromised by late spring freeze events occurring at the onset of bud burst or even after buds have opened. Severe crop loss represents an important economic challenge for grape growers in cold growing regions (MOLITOR et al., 2014). 'Edelweiss' grapevines are one of the earliest varieties to break bud in the vineyard making them highly vulnerable to late spring freeze events. Bud break data were collected in 2016 and 2017 to check for any effects groundcovers had on the timing of bud break. In 2016, bud break occurred between April 11 and April 16 in all of the treatments. Trt 2 completed bud break the earliest and Trt 4 was the latest, however Trt 1, 3, 4 and the control showed no statistical difference in the date of bud break (Figure 2.7) ($p \leq 0.05$). Vines growing within the Trt 2 groundcover broke bud significantly earlier (up to 4 days) than all other treatments.

In 2017, bud break occurred within a three day timeframe ranging from April 23 to April 26. Trt 1 had the earliest bud break in 2017 and was significantly earlier than Trt 2 ($p = 0.0200$) but was not different from the control ($p = 0.4325$). Although some statistical differences were observed in both 2016 and 2017 the actual difference (in days) was not large enough that a grower would consider that the groundcovers positively or negatively affected the rate of bud break. The likelihood that a bud delay of 3 to 4 days would help vines avoid a late spring freeze would be low.

**Figure 2.7. Julian date of bud break in 2016 and 2017. Bud break was determined when 60% of buds had reached stage 4 on the modified Eichhorn-Lorenz Scale of Grapevine Development. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**



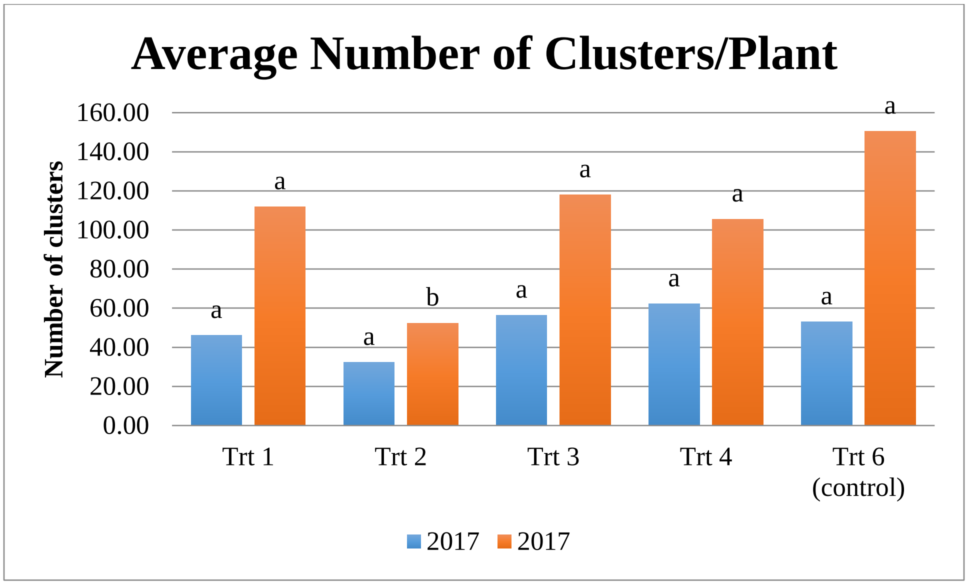
*Columns in the same year with same letters are not significantly different at $p \leq 0.05$.

## Harvest Results

### Number of Clusters per Plant

The average number of clusters per plant is important to grape growers for a few reasons, one of which and possibly the most important is in the ease of harvest. Many small clusters on a plant are much more difficult and time consuming to hand harvest than if there are fewer, larger and fuller clusters on the plants. It isn't possible to gauge the size of the clusters by just looking at the average cluster number per plant data, but typically if there is a huge amount of clusters on a plant it means their size has greatly decreased. From looking at Figure 2.8 all of the vines in each treatment showed an increase in number of clusters from 2016 to 2017. The largest change from year to year was found in the control treatment which increased from 51 clusters per plant to 150 clusters per plant. Trt 1 increased from 46 clusters per plant to 112 clusters, Trt 2 – 32 clusters to 54 clusters, Trt 3 – 53 clusters to 116 clusters and Trt 4 – 61 clusters to 106 clusters.

**Figure 2.8. Average number of clusters harvested from each 'Edelweiss' vine under four different groundcover treatments and a herbicide sprayed control. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**



*Columns in the same year with same letters are not significantly different at $p \leq 0.05$.

The simple effect comparisons of treatment*year shows no significant differences between treatments in 2016. In 2017, there were four treatment comparisons that showed significant differences at $p \leq 0.05$. Trt 2 had significantly fewer clusters than all of the other treatments (Trt 1, 3, 4 and control) (Figure 2.8). This was expected as visual difference between Trt 2 and the rest was quite obvious in the number of clusters that were present on each plant.

When the data from 2016 and 2017 are combined similar results were seen where Trt 2 is significantly different from all of the other treatments (2, 3, 4 and Control) (Table 2.1).

**Table 2.1. Measured values for average number of clusters per vine, total cluster weight, average cluster weight, average weight of a single berry, soluble solids (°Brix), pH and titratable acidity (TA) in 2016 and 2017. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**

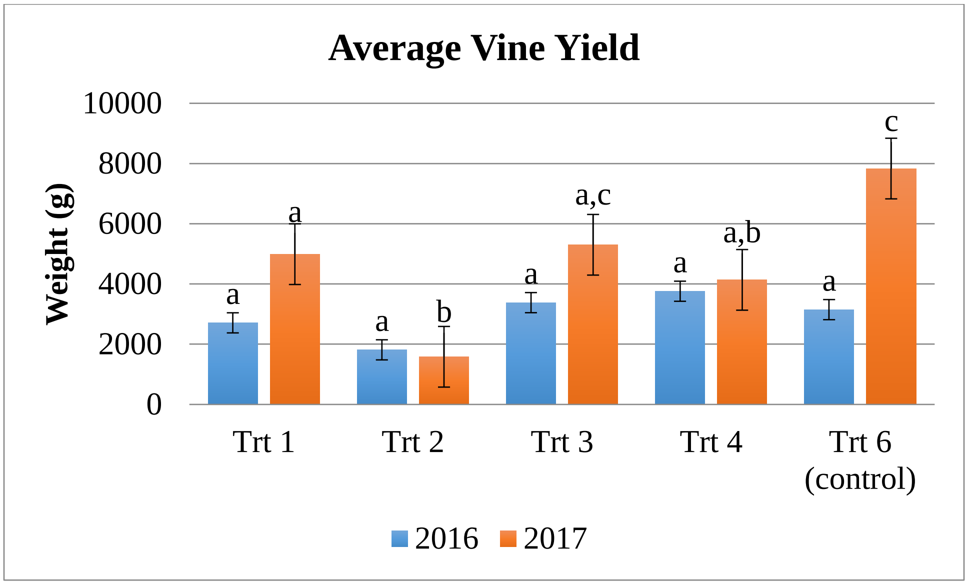
| **2016** | **Cluster Number** | **Avg Vine Yield (g)** | **Avg Cluster Weight (g)** | **Avg Berry Weight (g)** | **°Brix** | **pH** | **TA** |
|---|---|---|---|---|---|---|---|
| **Trt 1** | 46.1 a | 2709.6 a | 58.6 a | 1.8 a | 15.8 a,b | 3.2 | 10.3 a |
| **Trt 2** | 32.3 a | 2575.1 a | 58.0 a | 1.8 a | 15.8 a,b | 3.2 | 10.3 a |
| **Trt 3** | 53.3 a | 2345.1 a | 57.5 a | 1.8 a | 15.9 a,b | 3.2 | 10.2 a |
| **Trt 4** | 60.9 a | 2345.1 a | 58.6 a | 1.8 a | 15.9 b | 3.2 | 10.0 a |
| **Control** | 51.2 a | 2382.1 a | 59.1 a | 1.8 a | 16.0 a | 3.2 | 10.0 a |
| **2017** | **Cluster Number** | **Avg Vine Yield (g)** | **Avg Cluster Weight (g)** | **Avg Berry Weight (g)** | **°Brix** | **pH** | **TA** |
| **Trt 1** | 112.0 a | 4989.5 a | 43.7 a,b,d | 2.3 a | 18.0 | 3.4 | 7.6 a,b |
| **Trt 2** | 52.4 b | 1583.0 b | 29.1 a,b | 2.0 a | 17.1 | 3.3 | 8.5 b |
| **Trt 3** | 118.0 a | 5302.5 a,c | 56.0 c,d | 2.1 a | 18.2 | 3.5 | 6.5 a |
| **Trt 4** | 105.6 a | 4136.8 a,b | 36.3 a | 2.0 a | 15.7 | 3.4 | 8.2 b |
| **Control** | 150.5 a | 7833.5 c | 49.9 d,c | 2.1 a | 17.0 | 3.4 | 8.2 b |

*Values with the same letter in the same column indicate no statistical differences at $p \leq 0.05$.

### Average Vine Yield

From 2016 to 2017 the average cluster weight increased significantly in all of the treatments with the exception of Trt 2, which actually decreased. In 2016, Trt 2 had an average yield of 1848.2 grams (4 lbs) and dropped to 1682.6 grams (3.7) in 2017. This result is concerning because a drop in yield from the second to third year is the opposite of what should occur. The drop alone is negative but the total weight is also concerning. 'Edelweiss' grapevines should yield 20-30 lbs per plant after the third or fourth year they are planted. For example, the control yielded 3040 grams (6.7 lbs) per plant in 2016 and jumped up to 7833.0 grams (17 lbs) in 2017, which would be the typical expectation for 'Edelweiss' vines.

**Figure 2.9. Average yield per vine when grown under four different groundcover treatments and a herbicide sprayed control. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**



*Columns in the same year with same letters are not significantly different at $p \leq 0.05$.

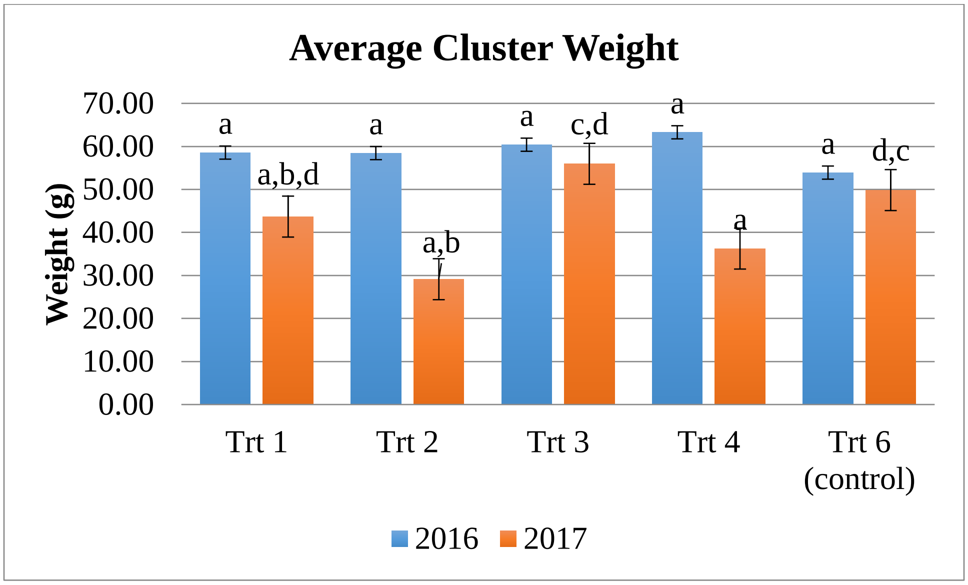
Statistically, there were no significant differences in total yield between treatments in 2016 (Appendix L). However, Figure 2.9 clearly shows that Trt 2 produced much less fruit than all of the other treatments and still should be considered an important result, especially after seeing the results from 2017 where Trt 2 yields decreased from 2016 (Table 2.1). In 2017, Trt 2 had significantly lower yields than all other treatments and the control with the exception of Trt 4 ($p \leq 0.05$). Treatments 1, 2 and 4 were all had significantly lower yields than the control. The only Trt that was not different from the control was Trt 4, which was grown as a control in the first year and then was converted to a Texoka Buffalograss groundcover treatment in the year following the grapes being planted (2015). This is one indication that planting a groundcover after the vines have one year to establish may limit the amount of competition between the vines and groundcovers, thus producing higher yields.

**Figure 2.10. Side by side comparison of vines at time of harvest in 2017. The herbicide sprayed control (top and bottom left) has significantly more canopy than the native grass treatment (top and bottom right).**

## Average Weight of Clusters

Similar to yield, there were no significant differences between treatments in average cluster weights in 2016 (Figure 2.11). In 2017, the average cluster weight dropped across the board, all treatments showed lower average weights than in 2016, however total yields increased from 2016 to 2017. A drop in cluster weight but an increase in total yield typically means one thing, more clusters, which reduces the average. This is proven by the cluster number data which shows a large increase in cluster number from 2016 to 2017. Increased cluster numbers can result from a variety of factors but most likely it was caused by more buds left at pruning than in the previous year and/or an environmental event caused vines to grow and produce additional clusters from secondary buds (hail, wind, herbicide drift, etc.). In 2016, the vineyard was severely damaged from herbicide drift with an estimated 50% yield loss. In 2017, the vineyard was hit once-again with herbicide drift which caused secondary buds to burst and produce secondary clusters, thus explaining the increase in cluster number and the decrease in weight (Table 2.1). Treatment 2 produced 54% less fruit than the control.

**Figure 2.11. Average weight of clusters harvested from ‘Edelweiss’ vines grown under four different groundcover treatments and a herbicide sprayed control. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep’s Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing’s Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**



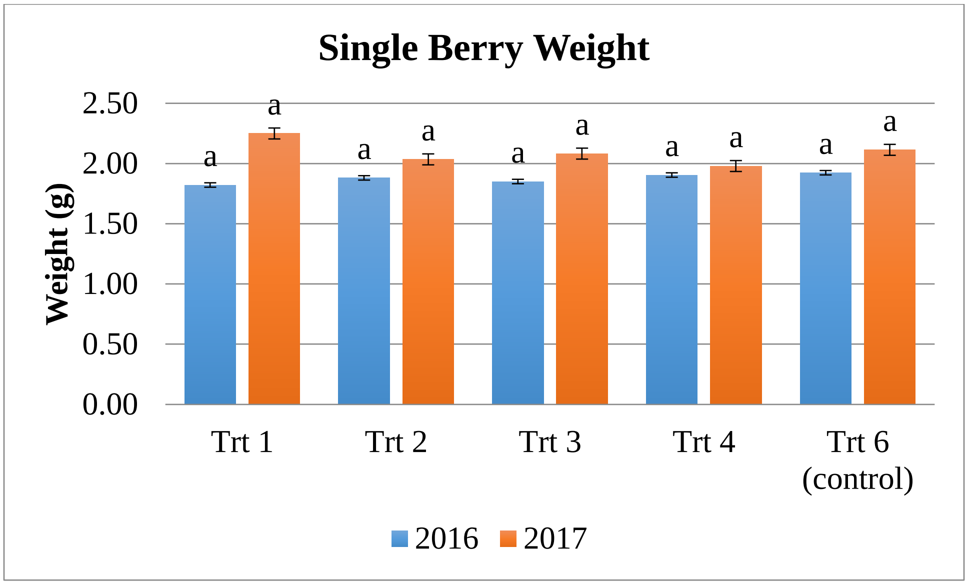
*Columns in the same year with same letters are not significantly different at $p \leq 0.05$.

**Figure 2.12. Image of leaf damaged by a herbicide drift event that occurred in the spring of 2016 when the vines were flowering. An estimated 50% crop loss was attributed to this event.**

### Average Single Berry Weight

In 2016 and 2017, single berry weights consistently ranged from 1.82 grams to 2.2 grams. In both years there were no significant differences ($p \leq 0.05$) between any of the treatments (Figure 2.13). Reduced berry size has been associated with decreasing water potential (SHELLIE, 2006). Berry size is an important factor in juice and wine quality, because much of the favorable anthocyanins, tannins and other polyphenols are located in the skins (CHEYNIER et al., 1998; CORTELL et al., 2008). The ratio of skin to pulp is higher in smaller berries, resulting in a higher fruit quality.

**Figure 2.13. Average weight of single berries harvested from 'Edelweiss' vines grown under four different groundcover treatments and a herbicide sprayed control. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**

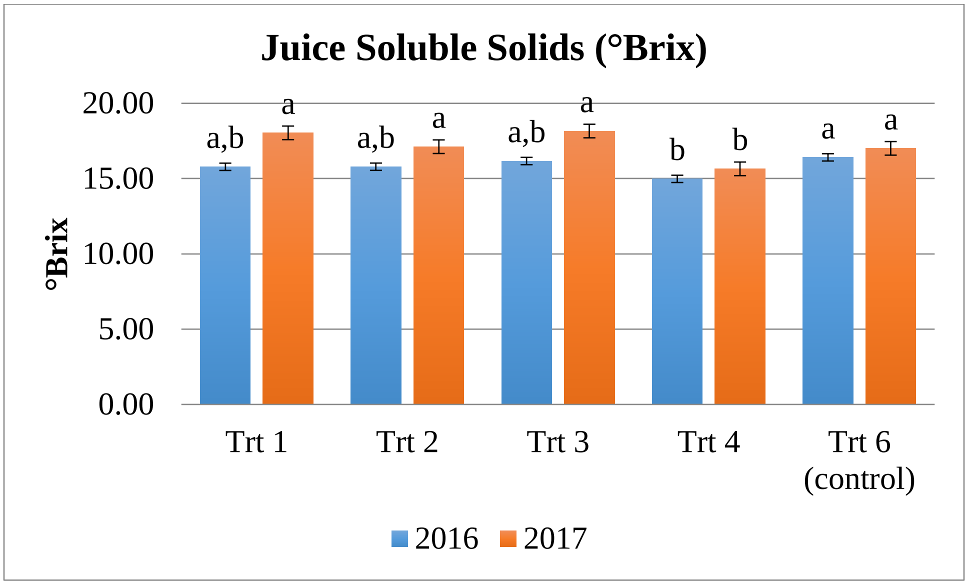


*Columns in the same year with same letters are not significantly different at $p \leq 0.05$.

### Soluble Solids (°Brix)

'Edelweiss' grapes are typically harvested before they are phenologically ripe when used for wine production. The level at which they are typically harvested is between 14 and 16 °Brix, depending on the winery's preference. In 2015, the fruit ranged from 15.1 °Brix (Trt 4) to 16.3 °Brix (control) and all samples fell within the recommended range. The only significant difference between treatments was Trt 4 had a lower °Brix than the control (p = 0.037), however the difference was small and probably would not be considered significant to the wine maker. Soluble solids were higher across the board in 2017 ranging from 15.7 °Brix (Trt 4) to 18.2 °Brix (Trt 3) and exceeded the typical level wanted by a winery. However, the winemaker made the ultimate decision on when to pick these grapes. Treatment 4 was again significantly lower than the control in 2017 (p = 0.028). Treatments 1, 2 and 3 were also all had significantly higher °Brix than Trt 4 at p ≤ 0.05.

**Figure 2.14. Measured values of soluble solids (°Brix) from juice collected from 100-berry samples of 'Edelweiss' grapevines grown under four different groundcover treatments and a herbicide sprayed control. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**



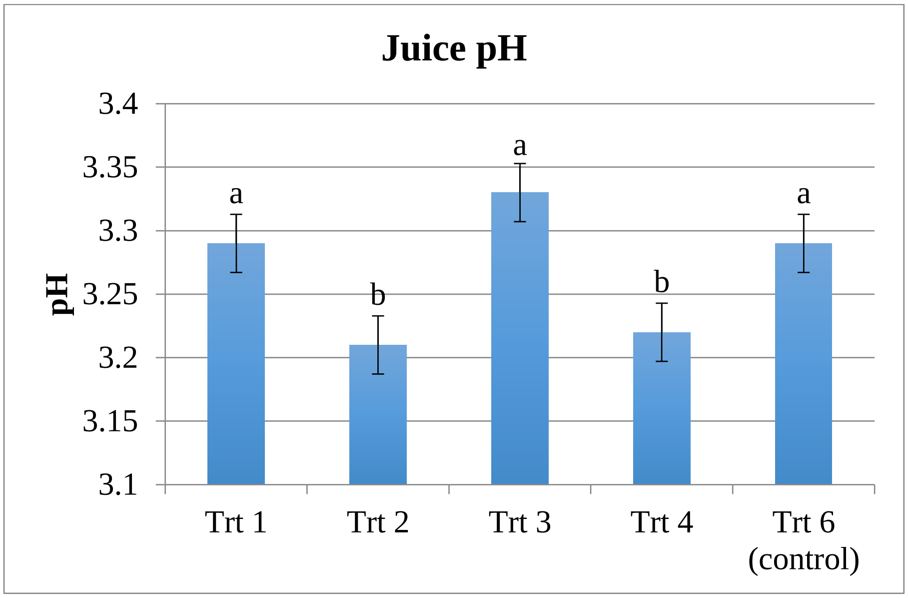
*Columns in the same year with same letters are not significantly different at *p*≤ 0.05.

## pH

The optimum juice pH range for producing white wine with grapes grown in the Midwest is 3.2 – 3.4 (DHARMADHIKARI AND WILKER, 2001). In 2016, juice pH in all of the treatments was slightly lower than the recommended range at 3.2. pH values in 2017 were higher than in 2016 with pH levels ranging from 3.3 to 3.5 . Statistically, there were no differences between pH values in 2016 and 2017 so the data from both years was combined and the main effects were observed and shown in Figure 2.15. Trt 2 and Trt 4 had significantly lower juice pH than the control (p = 0.026 and p = 0.023), however both were still within the recommended range.

Although some statistical differences were seen within pH, the value of this is diminished because all samples would still be considered satisfactory by the winemaker.

**Figure 2.15. Measured values of pH from juice collected from 100-berry samples of 'Edelweiss' grapevines grown under four different groundcover treatments and a herbicide sprayed control. Values from 2016 and 2017 were averaged. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**

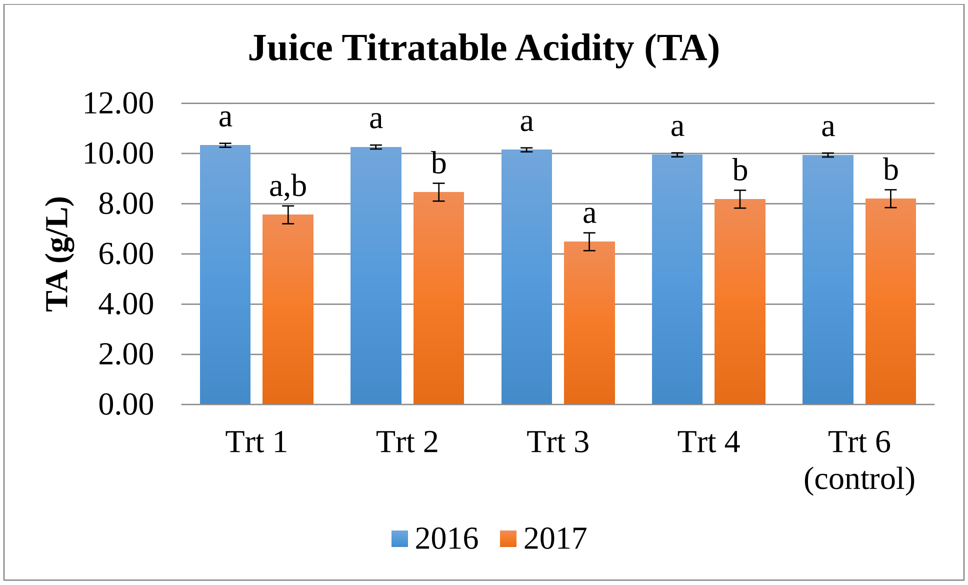


*Columns in the same year with same letters are not significantly different at $p \leq 0.05$.

### Titratable Acidity (TA)

The recommended range for titratable acidity (TA) is 7.0 to 9.0 g/L. In 2016, groundcover treatments had no significant effects on TA where the mean among treatments was 10.1 g/L. However, all samples were above the recommended range in 2016. Inverse to the pH results, the TA in 2017 was significantly lower than in 2016 and TA values fell to within the recommended ranges (Figure 2.16). Trt 3 was the only groundcover which significantly affected TA when compared to the control ($p = 0.006$). Even though some statistical differences were seen amongst the treatments in 2017, all values were still in the acceptable range.

**Figure 2.16. Measured values of titratable acidity (TA) from juice collected from 100-berry samples of 'Edelweiss' grapevines grown under four different groundcover treatments and a herbicide sprayed control. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**



*Columns in the same year with same letters are not significantly different at *p*≤ 0.05.

## Soil Samples

Soil samples were collected in the late winter of 2015, 2016 and 2017 at a depth of 12 inches. Samples were tested for a variety of factors including: pH, organic matter, bulk density (Appendix M), Cation Exchange Capacity (CEC), nitrate ($NO_3$), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and zinc (Zn). Each of these elements is essential to grapevine health and fruit quality.

A soil pH of 5.5 to 6.5 is considered optimum for winegrapes and allows for more efficient absorption of nutrients than in soils that are more alkaline or acidic (SMART AND ROBINSON, 1991). Vines will grow in a wider pH range of 4.0 to 8.5, but a pH below 5.5 and above 8 will decrease yields and hinder vine health. Soil pH levels were not significantly different in any of the years so the data were averaged to acquire a single pH value for the 3 years of data. Trt 4 had significantly higher pH than all of the other treatments (Table 2.2), however it still fell within the recommended range of optimal pH. Overall, the soil of each groundcover treatment fell within the recommended range for optimal grapevine growth.

**Table 2.2. Average soil pH from 2015, 2016 and 2017. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**

| **Treatment** | **pH** | **Standard Error** |
|---|---|---|
| Trt 1 | 6.1 a | 0.058 |
| Trt 2 | 6.1 a | 0.058 |
| Trt 3 | 6.1 a | 0.058 |
| Trt 4 | 6.3 b | 0.058 |
| Control | 6.1 a | 0.058 |

*Value with the same letter indicate no statistical differences at $p \leq 0.05$.

Soil organic matter (OM) is important because it improves moisture retention, soil fertility, reduces compaction and overall soil structure. The optimal level of organic matter for winegrapes is 2-3%. Nitrogen is released from OM at roughly 20 lbs of N per acre for each 1% of OM present (WOLF, 2008). If OM is too high, grapes tend to be less winter hardy because excess nitrogen promotes vegetative growth too late into the fall, not allowing vines to acclimate for winter.

Similar to pH, there were no significant differences in OM between the three years of data collection, so values were combined. OM values all fell within the recommended range of 2-3% with some minor statistical differences between treatments (Table 2.3). The control and Trt 4 had the lowest OM, which was expected as there was less vegetation present in these plots.

**Table 2.3. Average soil organic matter from 2015, 2016 and 2017. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**

| Treatment | % Organic Matter | Standard Error |
|---|---|---|
| Trt 1 | 2.3 a,d | 0.062 |
| Trt 2 | 2.5 b | 0.062 |
| Trt 3 | 2.4 c,d | 0.062 |
| Trt 4 | 2.2 a | 0.062 |
| Control | 2.2 a | 0.062 |

*Values with the same letter indicate no statistical differences at $p \leq 0.05$.

Cation exchange capacity (CEC) is basically the soil's capability to hold nutrients. Each soil type will have a unique CEC, for example, fine-textured clay soils will have a CEC around 25 meq/100 g of soil. The greater the clay and organic matter content of the soil, the higher the CEC. Nutrient levels and pH tend to be more stable in soils with higher CEC. CEC levels below 6 meq/100g of soil may have rapid changes in K, Ca and Mg (BROWN, 2013). CEC levels were similar throughout the 3 years soil samples were collected and all stayed right around the 25 meq/100 g of soil level with no significant difference among treatments (Table 2.4).

**Table 2.4. Average soil Cation Exchange Capacity (CEC) collected in 2015, 2016 and 2017. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**

| Treatment | CEC (meq/100g) | Standard Error |
|---|---|---|
| Trt 1 | 26.4 a | 0.608 |
| Trt 2 | 26.2 a | 0.608 |
| Trt 3 | 25.8 a | 0.608 |
| Trt 4 | 25.8 a | 0.608 |
| Control | 26.5 a | 0.608 |

*Values with the same letter indicate no statistical differences at $p \leq 0.05$.

The recommended range for nitrate ($NO_3$) levels in the vineyard is generally between 20-60 lbs/acre (5-15 ppm) for self-rooted American and hybrid grapevines. Grapevines that are grown in soils with excess nitrogen levels may become overly vigorous which can lead to reduced fruit quality, higher disease incidence and reduced winter hardiness. Soil $NO_3$ levels were statistically different from year to year so the data were not averaged across years, as previously done. Generally speaking, all $NO_3$ levels were below the recommended rates for American and hybrid winegrapes throughout the three years. In 2016 and 2017, Trt 1 had significantly higher $NO_3$ rates than all other treatments (Table 2.5) and was the only Trt that had $NO_3$ rates within the recommended range. This was exciting to see because Trt 1 was specifically chosen because it had $NO_3$ producing species such as Birdsfoot Trefoil and Dutch clover. It is also important to note that soil samples were collected at a depth of only 12 inches and nitrate readily leaches down into the soil profile, so it is conceivable that $NO_3$ levels were higher deeper in the soil.

**Table 2.5. Soil nitrate ($NO_3$) levels collected from vineyard soil samples from 2015 to 2017. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**

| Treatment | 2015 | 2016 | 2017 |
|---|---|---|---|
| Trt 1 | 2.4 a | 7.4 a | 8.0 a |
| Trt 2 | 5.4 a | 1.8 b | 1.2 b |
| Trt 3 | 2.6 a | 3.4 a | 3.2 b |
| Trt 4 | 2.4 a | 1.6 b | 1.0 b |
| Control | 3.4 a | 2.6 b | 1.2 b |

*Values with the same letter in the same column indicate no statistical differences at $p \leq 0.05$.

The recommended range for P is 40-50 ppm, K between 250-300 ppm, Ca between 500-2000 ppm, Mg between 100-250 ppm and Zn around 2 ppm. Soil samples collected in all treatments were drastically below the recommended range for P (12.2 to 17.5 ppm). Trt 3 had the lowest P values while Trt 2 had the highest concentration. None of the treatments were significantly different from the control. Potassium was also below the recommended range in all treatments, but not as severely as P. Trt 4 had the lowest K levels at just 200 ppm and was the only Trt that was significantly different from the control (Table 2.6). Ca and Mg were both well above the recommended ranges. There were not any significant differences between in Ca across the treatments. Trt 3 showed significantly lower Mg concentrations than the control, which would actually be a positive in this case, however it was still considerably higher than the recommended range. Zn hovered right around the recommended 2 ppm for vineyard soil samples. Soil sample results can be compared to petiole samples that were collected at bloom in 2017. Generally speaking all of the nutrients of the petiole analyses fell within or just outside the recommended range for bloom petiole levels (Appendix N).

**Table 2.6. Average Potassium (K), Calcium (Ca), Magnesium (Mg), Sodium (Na) and Zinc (Zn) concentrations of soil samples collected from 2015-2017. Trt 1 = Western Yarrow, Birdsfoot Trefoil and Dutch Clover; Trt 2 = Hard Fescue, Sheep's Fescue, Sideoats Grama, Buffalograss and Blue Grama; Trt 3 = KY Bluegrass, White Clover, Red Fescue, Hard Fescue and Chewing's Fescue; Trt 4 = Texoka Buffalograss; Control = weeds controlled by herbicide under-row.**

| Treatment | P (ppm) | K (ppm) | Ca (ppm) | Mg (ppm) | Zn (ppm) |
|---|---|---|---|---|---|
| Trt 1 | 13.4 a,c | 215.7 a,c | 3455.4 a | 674.0 a,d | 2.5 a |
| Trt 2 | 17.5 b,c | 243.0 b,d | 3232.9 a | 662.7 a,c,d | 2.2 a |
| Trt 3 | 12.2 a | 218.8 a,c | 3285.9 a | 617.1 d | 2.0 a |
| Trt 4 | 14.3 a,c | 200.0 c | 3351.3 a | 689.6 c,e | 1.5 a |
| Control | 15.1 a,c | 227.8 a,d | 3298.5 a | 717.9 a,e | 2.2 a |

*Values with the same letter in the same column indicate no statistical differences at $p \leq 0.05$.

## Insect Populations

Insect populations were collected in 2016 by a University of Nebraska undergraduate Entomology student as part of his senior thesis project. The goal of these collections was to evaluate the types and numbers of insects present in the vineyard (including beneficials) where the groundcovers were grown and also in a vineyard where the under-vine areas were controlled with herbicides. His results indicated that there were seven main insect orders present in the vineyard with groundcovers and included: Orthoptera, Diptera, Hymenoptera, Coleoptera, Mantodea, Lepidoptera and Hemiptera. It was visually noted by many of the workers in the vineyard that there was a large increase in pollinating insects in the treatments containing flowering species such as yarrow and trefoil. So much so, working in these treatments became slightly hazardous because the bees began stinging the workers. This would be an important consideration when choosing a groundcover, especially in vineyards close to the winery/tasting room where guests may be venturing into the vineyards.

**Figure 2.17. Image of a lady beetle resting on white clover in Treatment 3. These insects prey on herbivorous insects such as aphids and scale insects.**

## Conclusions

1. A main objective of this project was to evaluate the effect groundcovers that were planted both in the alleyways and vine-rows had on the water status of neighboring grapevines. In 2015 and 2016, there were no differences noticed among groundcover treatments and the herbicide-managed control. In 2017, the vines growing with groundcovers all showed a decrease in $\Psi_{md}$ as the season progressed. The control also decreased during the dry period of summer but never had as low of a $\Psi_{md}$ as any of the treatments. From this information, it can be said that the herbicide sprayed control is less affected by seasonal drought periods and is quicker to recover when the moisture returns. In 2017, the groundcovers clearly competed with the grapevines for water. Interestingly, none of the grapevines in any treatment reached a $\Psi_{md}$ below -10 bars, indicating the vines never even reached a mild water stress level, making it much more difficult to notice minute $\Psi_{md}$ differences.
2. Vine growth was severely impacted by groundcovers in all treatments. This was seen most harshly in Trt 2, where vines actually had a decrease in pruning weights from 2015 to 2016. The visual differences in the vines growing within the native grass groundcover was easily recognized. Throughout the growing season, the canopy of these vines never came close to reaching the ground, while the control vines had a full dense canopy that touched the ground by mid-season. In many of the Trt 2 vines there weren't even canes to prune and weigh. The $\Psi_{md}$ data does not explain this drastic difference in vine growth, so there is clearly something happening on a different level that needs to be explored further.
3. In addition to decreased vine growth, groundcovers all reduced the total yield of the vines. Again, this was most pronounced in the vines growing within the Trt 2 (native

grass) groundcover, where vines produced 133% less fruit compared to the control. Lower yields can sometimes lead to increased fruit quality, however, yields this low would not be acceptable to a grower or winemaker would want. Harvest data suggest that the lower yields in all of the treatments did not increase the fruit quality when compared to the control.

4. Slight differences were noticed in the soil samples between vines with groundcovers and the control. In most cases, the statistical difference was only marginally significant. Generally speaking, many of the measured soil nutrients were either well below or above the recommended range for optimal grapevine health. Contrary to the soil samples, most of the nutrients in the petiole analyses were within the recommended range. This difference may be caused by the collection timing of the soil and petiole samples. Soil samples were collected in the late winter while vines were still dormant (following soil sampling protocol) and the petiole samples were collected at bloom. If comparisons are to be made between soil and petiole samples it may be necessary to collect both at the same time. Sampling deeper into the soil profile might provide more complete information on the soil nutrition.

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# CHAPTER 3

## Non-Invasive Estimation of Leaf Water Potential in 'Edelweiss' Grapevines Using Infrared Thermography

### Introduction

For many of the vineyards in Nebraska and across the Midwest, irrigation is an important tool to increase grapevine vigor and fruit yield. However, with enhanced pressure on water resources, agricultural acres, including vineyards, are likely to experience water restrictions in the future, if they have not already. Fortunately for grape growers, grapevines are a drought tolerant plant and will actually produce higher quality fruit if deficit irrigation practices are used. Deficit irrigation basically is the restriction of water during specific times throughout the growing season. Deficit irrigation is a common practice in more prominent wine grape regions across the world, but has yet to be fully adopted in the Midwest, where hybrid grape cultivars ("varieties") are grown.

Water stress poses a serious threat to the survival, productivity and fruit quality in winegrapes. Plants experience water stress when the transpiration demands exceed the amount of moisture available in the root zone (KACIRA et al., 2002). Understanding water stress levels in grapevines is important to the viticulturist, particularly as it relates to irrigation management, in order to optimize vine yields. Once the pressure chamber (SCHOLANDER et al., 1965) was developed, measurement of leaf water potential has been used as a tool to assess the water status of plants (JONES, 1990) and to monitor the water relations of grapevines (SMART AND COOMBE, 1983). Grapevine leaf water potential has been shown to be relatively consistent when leaves are uniformly exposed to solar radiation (LIU et al., 1978).

In Nebraska, the use of irrigation regimes tends to be more instinctive, rather than scientific and technical. That is, when the dry days begin to accumulate in the summer months, growers will begin to irrigate in the vineyard, usually with no measurements of the actual water stress within the vines. This practice not only unnecessarily wastes water, but it can actually reduce fruit quality, increase vine vigor (when it's not necessary), increase disease pressure and make vines more susceptible to drought conditions by inhibiting their ability to grow deeper root systems. The key to improving wine grape quality in irrigated vineyards is to maintain a mild water stress so that the berry skin to pulp ratio is high, thus concentrating sugars and phenols at a higher level.

Using midday leaf water potential ($\Psi_{md}$) to determine grapevine water status and stress can be problematic as the measurements can vary greatly from one grape cultivar to another and across different climatic conditions. A major reason that growers have not yet adopted this practice is that there is very little information available outlining exactly what a "mild water stress" level is in the specific hybrid grape cultivars that are grown in the Midwest. There is a vast amount of research and data on common *vinifera* varieties but this area has yet to be fully explored in hybrid grapes. The main objective of this research was to determine the point at which 'Edelweiss' grapevines became water stressed and identify the corresponding measurement of leaf water potential. In addition, $\Psi_{md}$ was correlated to the Crop Water Stress Index (CWSI), to determine if this index accurately predicts the water stress level in 'Edelweiss' grapevines.

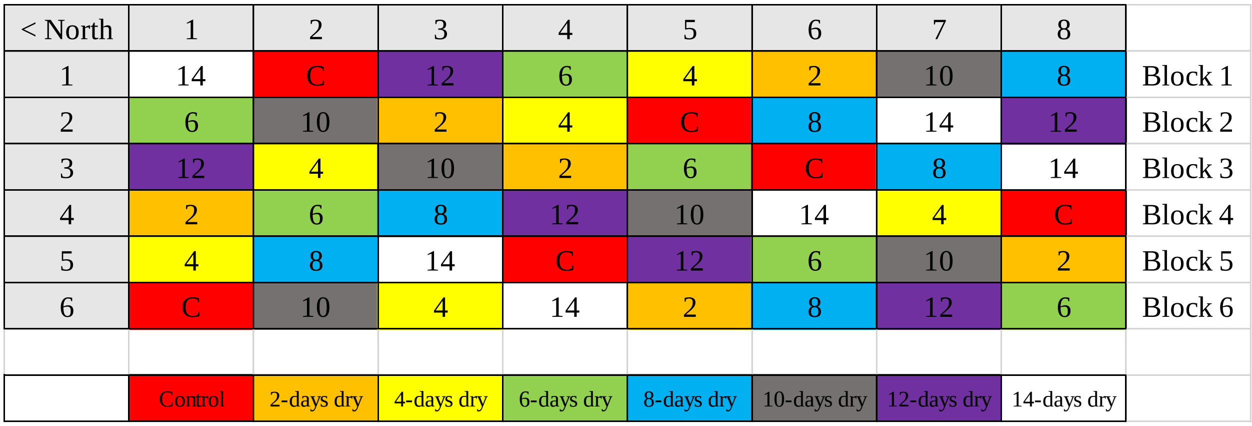
## Materials and Methods

The experiment was conducted in a greenhouse at the University of Nebraska – Lincoln (40.82°, 96.68°W, and elevation of 370.03 m above sea level), USA, during March, April and

May of 2016. Sixty bare-rooted ‘Edelweiss’ (Minnesota 78 x Ontario) grapevines from Double A vineyards were planted in five gallon pots on March 17, 2016. To maintain unvarying plant growth and development, an equal amount of soil mix (23% soil, 38% sphagnum peat moss, 19% sand, 20% horticultural vermiculite) was placed within each pot. The vines broke dormancy on March 23, 2016 (buds began to open). Once the grapevines began to grow shoots, all of the shoots except the strongest were removed. The single shoot was then tied to a bamboo pole which was inserted into the pot. The pots were arranged in 8 columns and 7 rows with spacing of 3 feet between pots. The positions of the pots were changed randomly throughout the experiment to minimize the impact of solar radiation difference across the greenhouse floor. Vines were watered at least twice per week in the early stages of the experiment and were watered more frequently as they began to grow larger. Fertigation using a 1:15 Hozon™ proportioner (Earth City, MO) began on April 4, using a 20-10-20 fertilizer at a rate of 400 ppm nitrogen. A granular fertilizer application was done on April 20, where 15 grams of 20-10-20 fertilizer was added to the top of each pot. As the vines grew taller [above the top of the bamboo pole (4 feet)] the shoots were cut off at the top of the pole to encourage lateral growth and increase leaf area.

**Figure 3.1. Image showing layout of 'Edelweiss' grapevines when the 14 days drying period began. Plants were randomly moved throughout the 14 days to minimize effects of differences in solar radiation across the greenhouse floor.**

**Figure 3.2. Experimental design and layout of the selected 48 potted 'Edelweiss' grapevines during the 14-day water stress timeframe. Blocking occurred from East to West to account for difference in solar radiation and temperature gradients.**



| < North | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 14 | C | 12 | 6 | 4 | 2 | 10 | 8 | Block 1 |
| 2 | 6 | 10 | 2 | 4 | C | 8 | 14 | 12 | Block 2 |
| 3 | 12 | 4 | 10 | 2 | 6 | C | 8 | 14 | Block 3 |
| 4 | 2 | 6 | 8 | 12 | 10 | 14 | 4 | C | Block 4 |
| 5 | 4 | 8 | 14 | C | 12 | 6 | 10 | 2 | Block 5 |
| 6 | C | 10 | 4 | 14 | 2 | 8 | 12 | 6 | Block 6 |
| | | | | | | | | | |
| | Control | 2-days dry | 4-days dry | 6-days dry | 8-days dry | 10-days dry | 12-days dry | 14-days dry | |

## Irrigation Treatments

All pots were watered in the same manner in the early stages of development. In the weeks before the water deficit regime began, pots were always watered to field capacity. Excess water was allowed to drain through the bottom of the pots. On May 26 the 48 most similar looking plants were chosen from the original 60 and randomly grouped into 8 water deficit treatments: 2, 4, 6, 8, 10, 12, 14 day dry (DD) and a control (0 DD) (Figure 3.2). Plants were chosen based upon their visual health (fully expanded, healthy leaves) as well as similar leaf numbers. A handful of plants exhibited nutritional deficiencies and were not included in the study. Each of the 8 treatments had 6 single plant replicates (each plant was an experimental unit). The plants were arranged in a randomized complete block design where blocking was done from East to West to account for differences in solar radiation and temperature gradients across the greenhouse floor. A moisture deficit strategy was implemented on the same day, where all plants were watered to field capacity to start the experiment. Two days later, the 14 DD treatment had its water withheld while all other pots were watered to field capacity. Two days after that, the next treatment (12 DD) had its water withheld. This process continued until only the control pots (0 DD) remained. On day 14, water deficit amongst the treatments ranged from fully irrigated to 14 days dry. Many of the leaves on the plants that had been dry for the full 14 days were beginning to desiccate and fall off. One additional plant was kept in both the control and 14 DD treatment groups. These extra plants were later used as fully transpiring and non-transpiring plants during the image acquirement to ease the calculation of the Crop Water Stress Index (CWSI).

### Thermal Image Acquisition and Processing

Thermal images were acquired and measurements of leaf water potential were taken on day 14 after the water stress regime began. Images of the plant canopies were acquired using two different thermal cameras (an expensive, non-grower affordable model and a lower-end, grower affordable model); the FLIR ThermaCAM S65 and the FLIR C2 (FLIR Systems, Inc.).

The spectral range and resolution of the S65 camera is 7.5 to 13 µm and 1.1 milliradians, respectively. The acquired thermal images using this device were 320 x 240 pixels at 14-bit radiometric resolution. The instrument is sensitive to a temperature range between -40 °F to +248 °F, with an accuracy of ±3.6 °F. The camera had an 8 mm lens with an angular field of view of 20° x 15°. The spectral range and resolution of the C2 camera is 7.5 – 14 µm and 1.1 milliradians, respectively. The acquired thermal images using this device were 80 x 60 pixels at 14-bit radiometric resolution. The instrument is sensitive to a temperature range between 14 °F to +302 °F, with an accuracy of ±3.6 °F. The camera had an 8 mm lens with an angular field of view of 41° x 31°. Emissivity was set at 0.96, corresponding to the normally accepted value for vegetation (JENSEN, 2009). Both cameras were mounted to a tripod at a distance of 10 feet from the potted vines and pointed towards the face of the canopy. At this distance three potted vine were able to fit within the field of view of the camera.

Leaf temperature varies with wind speed, humidity, irradiance and air temperature (JONES et al., 2009). These conditions change rapidly in both the field and the greenhouse, which makes the conditions of each image taken somewhat different. During image acquisition, three plants were imaged. The center plant was the vine of interest and on either side was a plant that was completely water stressed (14 DD) and on the other side was a plant that was not water stressed (0 DD). This was done to calibrate the leaf temperature of the plant of interest against the same for a fully transpiring and non-transpiring plant under the environmental conditions of when the image was taken. These two plants represented the fully transpiring and non-transpiring plants for the calculation of the CWSI.

Thermal and true color images were taken of 48 total potted grapevines. Many studies have recommended solar noon as the ideal time for thermal image acquisition because this is when plants experience maximum water stress and the environmental conditions (irradiance, relative humidity, and air temperature) that affect the leaf temperatures are relatively stable (ALCHANATIS et al., 2010; BEN-GAL et al., 2009; GRANT et al., 2006). The first image of this experiment was taken at 10:50 a.m. CST and the last image was taken at 1:15 p.m. CST. The environment conditions at the time of data collection were typical for a late May day in Eastern Nebraska and fairly ideal for the computation of the CWSI, with the exception of a stray cloud. The outside air temperature was 83 °F with mostly sunny skies and relative humidity during collection time ranging from 60% - 62%. Greenhouse conditions were warmer with an air temperature ranging from 94 – 100 °F and relative humidity of 35% - 42%. One environmental factor that was not ideal for data collection was the random cloud that reduced downwelling irradiance during the acquisition of some images. This is shown by the large range of irradiance during the time of image collection (147 - 1055 w/m$^2$). As expected the solar irradiance also increased as the experiment progressed through the two hour collection period.

The raw thermal images, one for each plant from each camera (96 total), were processed using the Crop Water Stress Index (CWSI) (IDSO et al., 1981; JACKSON et al., 1981) and is defined as:

$$CWSI = \frac{T_{canopy} - T_{wet}}{T_{dry} - T_{wet}}$$

where $T_{canopy}$ is the actual leaf temperature under given environmental conditions; $T_{wet}$ is the lower boundary for canopy temperature, corresponding to a well-watered plant with fully open stomata. $T_{dry}$ is the upper boundary for canopy temperature, representing the temperature of a non-transpiring leaf with stomata that are completely closed. The CWSI was computed using leaf temperature values from three leaves on each plant. Only fully expanded, healthy leaves, located in full sun were chosen for data collection.

### Leaf Water Potential Measurements

Leaf water potential measurements were done immediately following the acquisition of the thermal and digital images. A healthy fully expanded leaf was chosen from each plant of interest. This leaf blade was covered with a plastic bag, quickly sealed, and the petioles then cut within 1 – 2 seconds. The time from leaf excision from the plant to when it was placed in the pressure chamber was around 15 seconds. The petiole was placed through the chamber lid and secured tightly, with the cut end of the petiole facing outside and the bagged leaf in the chamber. The chamber was then sealed and slowly pressurized using nitrogen gas. As the pressure inside the chamber increased and began to exceed the negative pressure inside the leaf, sap was forced out of the cut edge of the petiole on the outside of the chamber. The point at which the drop of sap first began to exude from the cut end of the petiole, the pressure (bars) was recorded and used as the value for the leaf water potential. Leaves chosen for midday leaf water potential measurements were the youngest fully expanded leaves on the plant and were growing in full sun.

### Data Analysis

The raw thermal images were processed using FLIR Systems proprietary software. Within each image (one for each plant) contained the plant of interest, a fully water stressed plant and a fully irrigated plant. The water stressed plant acted as the non-transpiring variable in the CWSI and the non-water stressed plant was the fully transpiring variable in the formula. For each image two leaves were chosen from the plant of interest that were in full sun and an ellipse was drawn over the leaf in the FLIR software which averaged all pixels that fell within the ellipse. This was also done to both the water stressed and non-water stressed plants in the image. The temperature values obtained from the two leaves from each plant were then averaged together for a final temperature value of the plant. The three temperatures were then input into the CWSI formula to obtain the CWSI value.

Differences among the treatments were examined with one-way Analysis of Variance (ANOVA). Data were tested for homogeneity of variances using Shapiro-Wilk and Levene's tests. The Pearson Product Moment Correlation coefficients were used to evaluate the relationship between $\Psi_{md}$ and the CWSI. A stepwise regression was conducted to determine which environmental variables should be included as predictor variables. All data were analyzed using SAS (Version 9.2, Cary, NC) and Microsoft Excel (2013) was used for producing graphics.

## Results and Discussion

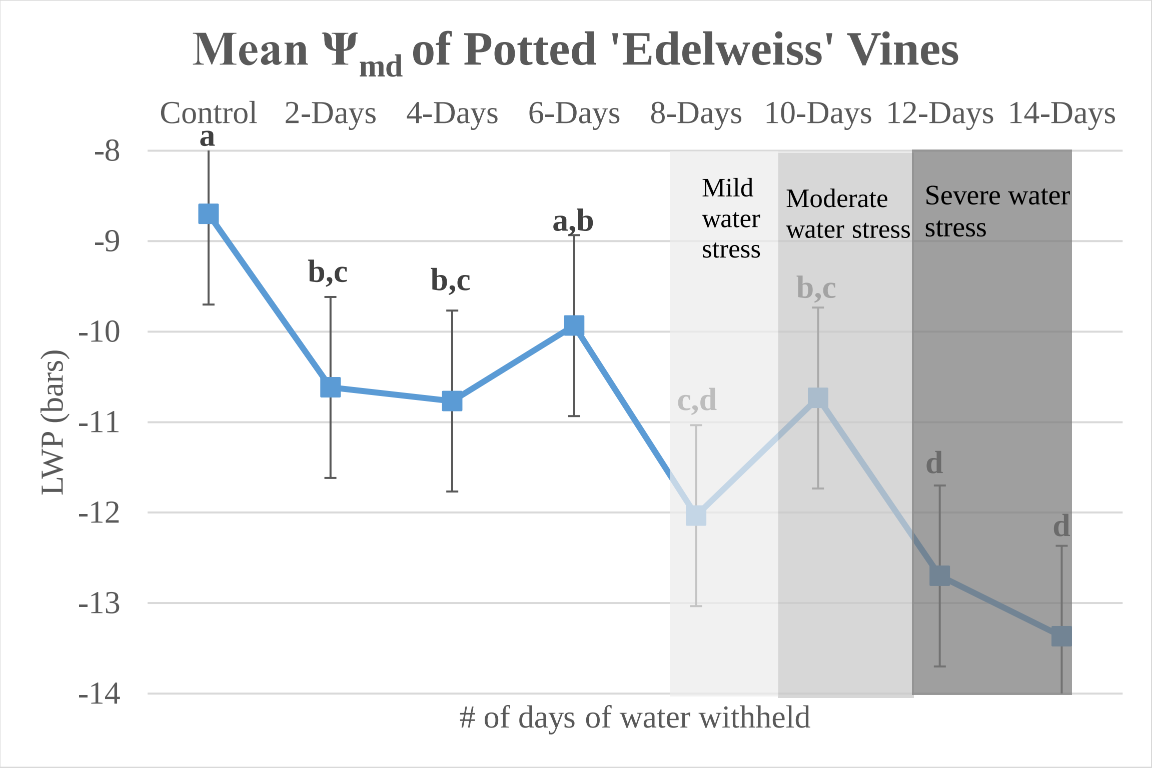
### Leaf Water Potential

The response of the 'Edelweiss' grapevines to water stress treatments, as detected by $\Psi_{md}$ is shown in Figures 3.4. Overall, the $\Psi_{md}$ values decreased in a linear fashion as the 14-day drying period progressed. The control plants (0 DD, fully watered) exhibited a $\Psi_{md}$ of -8.7 bars and that value decreased significantly after having water withheld for just two days (-9.93 bars). With this information a baseline can be laid-forth for 'Edelweiss' vines that are at full water potential fully transpiring at full water potential. The point at which the vines began to show the most water stress was at 8 DD. While the plants that were 2-6 DD showed no statistical differences, the 8 DD treatment had a significantly lower $\Psi_{md}$ than 6 DD (-12 bars). It was at this point that it was determined the plants had reached a significant/mild level of water stress. This was determined both by the comparing the $\Psi_{md}$ and visual water stress symptoms at the time of data collection. Plants that had been dry for 8 days showed the first signs of water stress which corresponded to the larger difference in $\Psi_{md}$ when compared to the control and 2, 4 and 6 DD water stress treatments. At 14 DD the vines exhibited severe water stress and had leaves that were exceptionally dry and were beginning to fall off (Figure 3.3). The $\Psi_{md}$ at this point was -13.3 bars, which was not statistically different from the 8 DD treatment (-12 bars) but the visual diffences between the two treatments was extreme. This is an indication that the $\Psi_{md}$ of the 14 DD treatment had "bottomed out" and was unable to go any lower because the leaves had very little moisture left in them. With this information it can be said that 'Edelweiss' vines would be mildy water stressed at -12 bars, moderately stressed at -12.5 bars and severely stressed at -13 bars or lower. It is interesting that the different stress levels all occur in such a small water potential spectrum, affirming that careful and precise water potential measurements need to be taken to keep plants at the optimum water stress level.

**Figure 3.3. Example of images collected for the Crop Water Stress Index (CWSI). The plant on the left is the control (0 DD), the plants in the middle and right had water withheld for 14 days. The center plant was changed for each image and the two outside plants served as baselines for use in the CWSI.**

An increase in $\Psi_{md}$ was noticed from 4 to 6 DD and from 8 to 10 DD (Figure 3.4). This is most likely the effect of the intermittent cloud cover which caused the grapevines to transpire more efficiently when the direct sun was blocked, thus causing a slightly less negative $\Psi_{md}$. Additionally, $\Psi_{md}$ measurements were taken over a fairly long period of time, so the plants that were measured first and the ones that were measured last had moderately different environmental conditions at the time of data collection. This could have been overcome by speeding up the data collection process and completing it in a shorter amount of time. To do this, there would not have been time to collect the CWSI data.

**Figure 3.4. Least Square Means of the Midday Leaf Water Potential ($\Psi_{md}$) of potted ‘Edelweiss’ grapevines that had water withheld from 0 to 14 days. A mild water stress threshold began at -12 bars.**



*bars represent the standard error of $\Psi_{md}$ for the 6 plant replicates.

**Table 3.1. Means, lower and upper bounds and standard deviation of $\Psi_{md}$ of potted ‘Edelweiss’ grapevines after a 14-day drying period.**

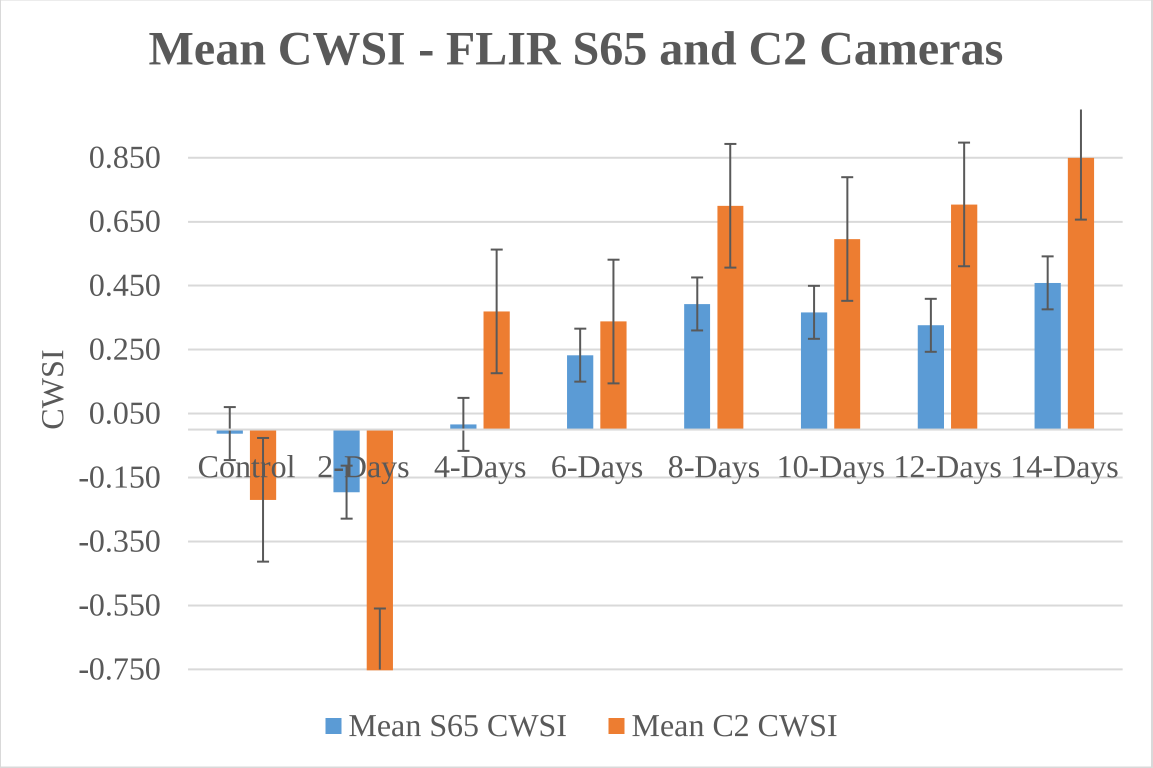
| **Treatment** | **Means (bars)** | **Lower** | **Upper** | **Standard Deviation** |
|---|---|---|---|---|
| Control | -8.70 | -9.78 | -7.62 | 1.185 |
| 2-Days | -10.62 | -11.70 | -9.53 | 1.160 |
| 4-Days | -10.77 | -11.85 | -9.68 | 1.675 |
| 6-Days | -9.93 | -11.02 | -8.85 | 1.171 |
| 8-Days | -12.03 | -13.12 | -10.95 | 0.742 |
| 10-Days | -10.73 | -11.82 | -9.65 | 0.755 |
| 12-Days | -12.70 | -13.78 | -11.62 | 0.827 |
| 14-Days | -13.37 | -14.45 | -12.28 | 2.254 |

In addition to determining the severity of water stress, two thermal imaging cameras were used to collect leaf temperature data used in the CWSI index. The CWSI index has been shown to be a sensitive indicator of $\Psi_{md}$ in warm arid growing regions (LEINONEN et al., 2006), but has not been well documented in more humid regions like Nebraska. A non-grower affordable (Flir® S65) and grower affordable (Flir® C2) camera were compared to determine if the cheaper, less sensitive camera was able to gather precise temperature values to be used in the CWSI. The Flir® C2 camera is now sold at Home Depot ($499) for industrial use, making it readily available to the public. The camera had just been released to market at the time of this project. The Flir® S65 camera is used primarily for research purposes and costs in excess of $50,000.

Pearson Product Moment Correlation coefficients were used to evaluate the relationship between $\Psi_{md}$ and the CWSI produced by both the Flir® S65 and C2 cameras. The correlations between the Flir® S65 CWSI and $\Psi_{md}$ were only marginally significantly different from zero ($p = 0.0510$). The correlation between the Flir® C2 CWSI and $\Psi_{md}$ was more significantly different from zero ($p = 0.0158$) indicating that the CWSI calculated from data of the C2 camera was more accurate than the expensive S65 camera. This can be clearly seen in Figure 3.5 where the C2 CWSI is consistently higher than the S65 CWSI. The closer the CWSI is to a value of 1, the more water stressed the plants, which mirrors the $\Psi_{md}$ data.

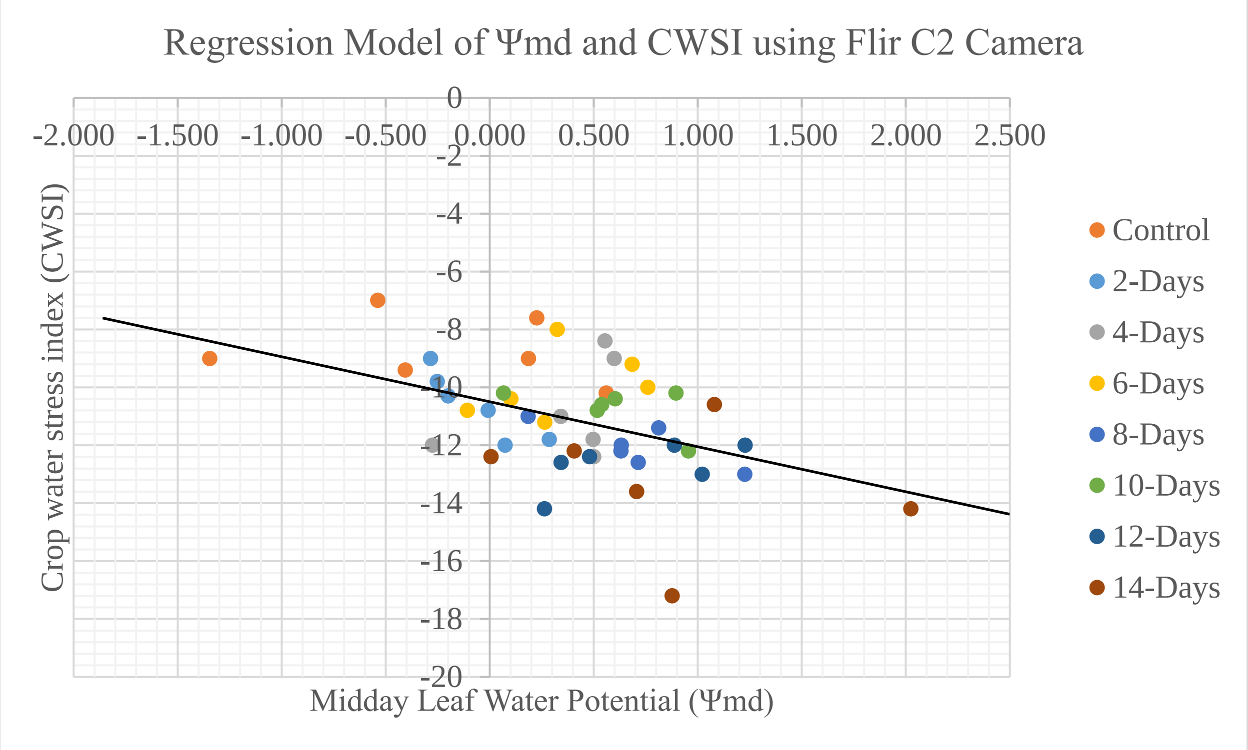
A stepwise regression was conducted to determine which environmental variables should be included as predictor variables (treatment, relative humidity, air temperature and irradiance). The stepwise regression indicated that the only variable that increased the $R^2$ values was the treatment variable. Using this regression model, an $R^2$ of 0.5114 was obtained correlating the Flir® C2 CWSI and the $\Psi_{md}$. This $R^2$ value is quite a bit lower than what other studies have found, however, those were all done in the field and not the greenhouse (JONES, 1999; LEINONEN et al., 2006). SWAIN et al. (2012) obtained an $R^2$ of 0.85 and 0.75 between the CWSI and soybean relative water content (RWC) and stomatal conductance, respectively in a very similar experiment in a Nebraska greenhouse. The CWSI may more effectively predict different plant water status measures such as RWC and stomatal conductance than $\Psi_{md}$ in more humid regions such as the Midwest. Further investigation is necessary to determine if this is true for woody grapevines.

**Figure 3.5. Graph comparing the difference in the Crop Water Stress Index (CWSI) of 0-14 day dry 'Edelweiss' grapvines. Leaf temperature data were collected with an expensive Flir® S65 and inexpensive C2 thermal cameras.**



*bars represent the standard error of the CWSI and $\Psi_{md}$ of the 6 plants replicates.

**Figure 3.6. Regression model of $\Psi_{md}$ versus CWSI. $\Psi_{md}$ predicted CWSI using measured leaf temperature from the Flir C2 thermal camera. The solid line is the best fit function for $\Psi_{md}$ prediction.**



## CONCLUSIONS

1. 'Edelweiss' grapevines that are at full water capacity and complete transpiration will have a $\Psi_{md}$ of around -8.7 bars under Eastern Nebraska environmental conditions. This information is important to growers because it provides a baseline for the $\Psi_{md}$ after being irrigated.
2. 'Edelweiss' grapevines experience mild water stress at -12 bars, moderate stress at -12.5 bars and severe stress at -13 bars or lower. This relatively small range for the three stress levels proves that careful attention needs to be paid to the vines to keep them at the optimal water stress level. Additional research is necessary to determine the volume of water that is needed when irrigating to keep the vines at the mild stress level. Also, more

research is needed to better understand the timing of implementing a mild water stress regime on the 'Edelweiss' vines. Up to this point, no research has been conducted to outline the specific times during the growing season when water should be withheld on this cultivar.

3. The leaf temperature date obtained by the Flir® C2 camera produced more accurate CWSI's than its more expensive counterpart. This may be attributed to the age of the two intruments. The C2 was purchased brand new and was a state-of-the-art camera at the time. The S65, while very expensive, was an older camera that was used heavily in the past. Even with the C2 temperature data, the $R^2$ values were still relatively low at only 0.51. Much more research is necessary to increase the correlations between the CWSI and $\Psi_{md}$ and get it to a point where the $\Psi_{md}$ can be accurately predicted using the CWSI.

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## CONCLUSIONS

1. Establishing groundcovers immediately following the planting of grapevines is challenging because an irrigation system is essential to speed the germination and establishment of the groundcovers. Without irrigation the groundcovers are slow to fill in the bare ground and weed populations quickly outcompete the planted cover. It is highly recommended that growers provide supplementary irrigation for successful groundcover growth.
2. All of the planted groundcover treatments became established and filled the ground area much faster than the natural vegetation and control treatments. In 2015, heavy rainfall events created severe soil erosion in this new vineyard. In the control, treatments that had little vegetation covering the ground, the water eroded soil so badly that there were 12 inch deep gullies running through the vineyard. As a result, remedial measures had to be taken, where the vineyard manager was forced to haul in soil to fill in the gullies. In the areas where the groundcovers were planted, little-to-no soil erosion was noticed.
3. Vine growth was affected by the groundcovers in 2014. The control and natural vegetation treatments had much higher shoot lengths and vine weights. This preliminary data indicates that planting groundcovers simultaneously with grapes is detrimental to the growth of young vines. This effect is probably magnified by the fact that the groundcovers were planted in the vine row, an area of the vineyard that is typically kept weed-free through the use of herbicides. Further investigation is needed comparing the effects of groundcovers planted in the first or second year of vineyard establishment.
4. A main objective of this project was to evaluate the effect groundcovers that were planted both in the alleyways and vine-rows had on the water status of neighboring grapevines. In 2015 and 2016, there were no differences noticed among groundcover treatments and

the herbicide-managed control. In 2017, the vines growing with groundcovers all showed a decrease in $\Psi_{md}$ as the season progressed. The control also decreased during the dry period of summer but never had as low of a $\Psi_{md}$ as any of the treatments. From this information, it can be said that the herbicide sprayed control is less affected by seasonal drought periods and is quicker to recover when the moisture returns. In 2017, the groundcovers clearly competed with the grapevines for water. Interestingly, none of the grapevines in any treatment reached a $\Psi_{md}$ below -10 bars, indicating the vines never even reached a mild water stress level, making it much more difficult to notice minute $\Psi_{md}$ differences.

5. Vine growth was severely impacted by groundcovers in all treatments. This was seen most harshly in Trt 2, where vines actually had a decrease in pruning weights from 2015 to 2016. The visual differences in the vines growing within the native grass groundcover was easily recognized. Throughout the growing season, the canopy of these vines never came close to reaching the ground, while the control vines had a full dense canopy that touched the ground by mid-season. In many of the Trt 2 vines there weren't even canes to prune and weigh. The $\Psi_{md}$ data does not explain this drastic difference in vine growth, so there is clearly something happening on a different level that needs to be explored further.
6. In addition to decreased vine growth, groundcovers all reduced the total yield of the vines. Again, this was most pronounced in the vines growing within the Trt 2 (native grass) groundcover, where vines produced 133% less fruit compared to the control. Lower yields can sometimes lead to increased fruit quality, however, yields this low would not be acceptable to a grower or winemaker would want. Harvest data suggest that

the lower yields in all of the treatments did not increase the fruit quality when compared to the control.

7. Slight differences were noticed in the soil samples between vines with groundcovers and the control. In most cases, the statistical difference was only marginally significant. Generally speaking, many of the measured soil nutrients were either well below or above the recommended range for optimal grapevine health. Contrary to the soil samples, most of the nutrients in the petiole analyses were within the recommended range. This difference may be caused by the collection timing of the soil and petiole samples. Soil samples were collected in the late winter while vines were still dormant (following soil sampling protocol) and the petiole samples were collected at bloom. If comparisons are to be made between soil and petiole samples it may be necessary to collect both at the same time. Sampling deeper into the soil profile might provide more complete information on the soil nutrition.
8. ‘Edelweiss’ grapevines that are at full water capacity and complete transpiration will have a $\Psi_{md}$ of around -8.7 bars under Eastern Nebraska environmental conditions. This information is important to growers because it provides a baseline for the $\Psi_{md}$ after being irrigated.
9. ‘Edelweiss’ grapevines experience mild water stress at -12 bars, moderate stress at -12.5 bars and severe stress at -13 bars or lower. This relatively small range for the three stress levels proves that careful attention needs to be paid to the vines to keep them at the optimal water stress level. Additional research is necessary to determine the volume of water that is needed when irrigating to keep the vines at the mild stress level. Also, more research is needed to better understand the timing of implementing a mild water stress

regime on the ‘Edelweiss’ vines. Up to this point, no research has been conducted to outline the specific times during the growing season when water should be withheld on this cultivar.

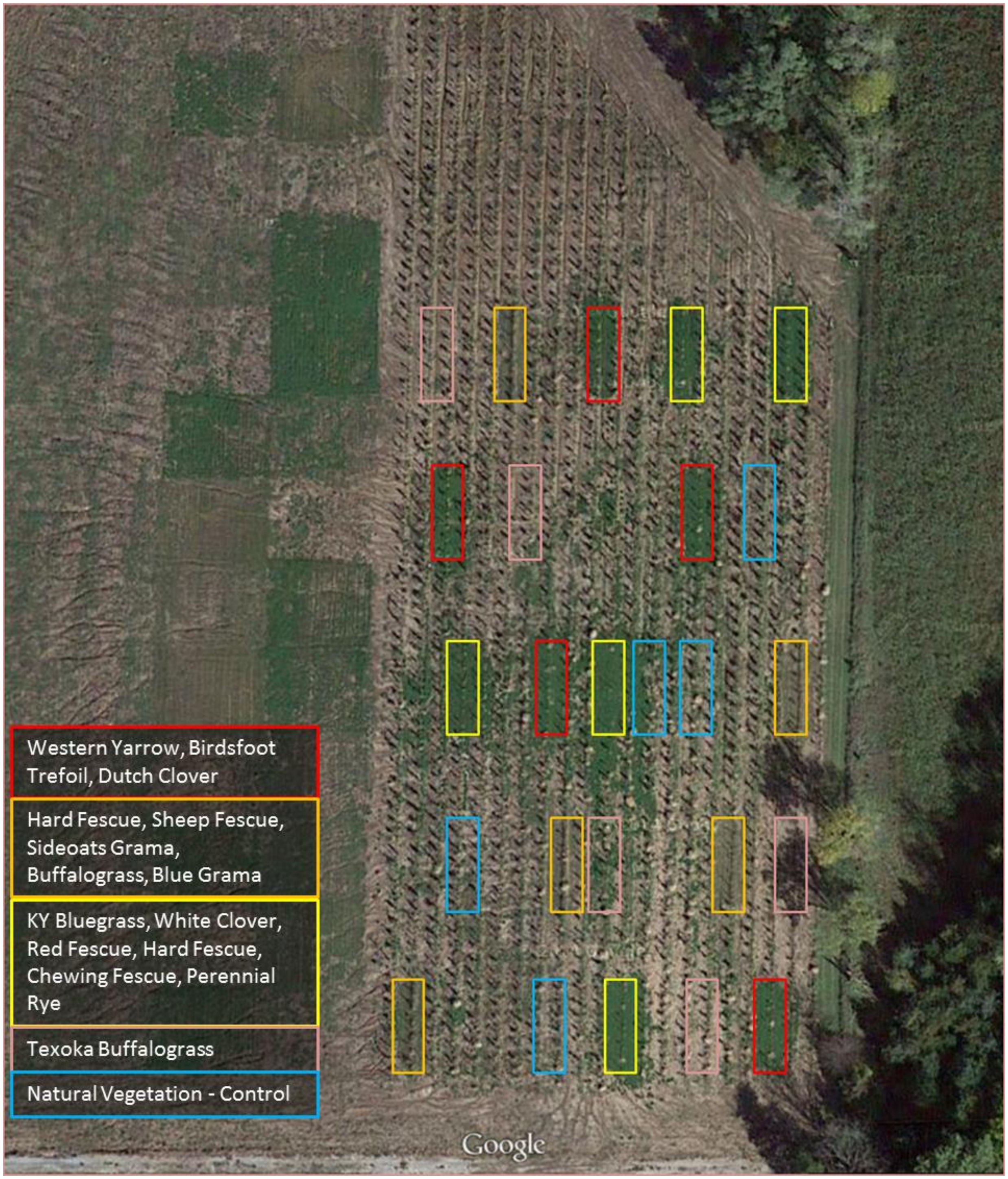
10. The leaf temperature date obtained by the Flir® C2 camera produced more accurate CWSI’s than its more expensive counterpart. This may be attributed to the age of the two intruments. The C2 was purchased brand new and was a state-of-the-art camera at the time. The S65, while very expensive, was an older camera that was used heavily in the past. Even with the C2 temperature data, the $R^2$ values were still relatively low at only 0.51. Much more research is necessary to increase the correlations between the CWSI and $\Psi_{md}$ and get it to a point where the $\Psi_{md}$ can be accurately predicted using the CWSI.

## FUTURE WORK

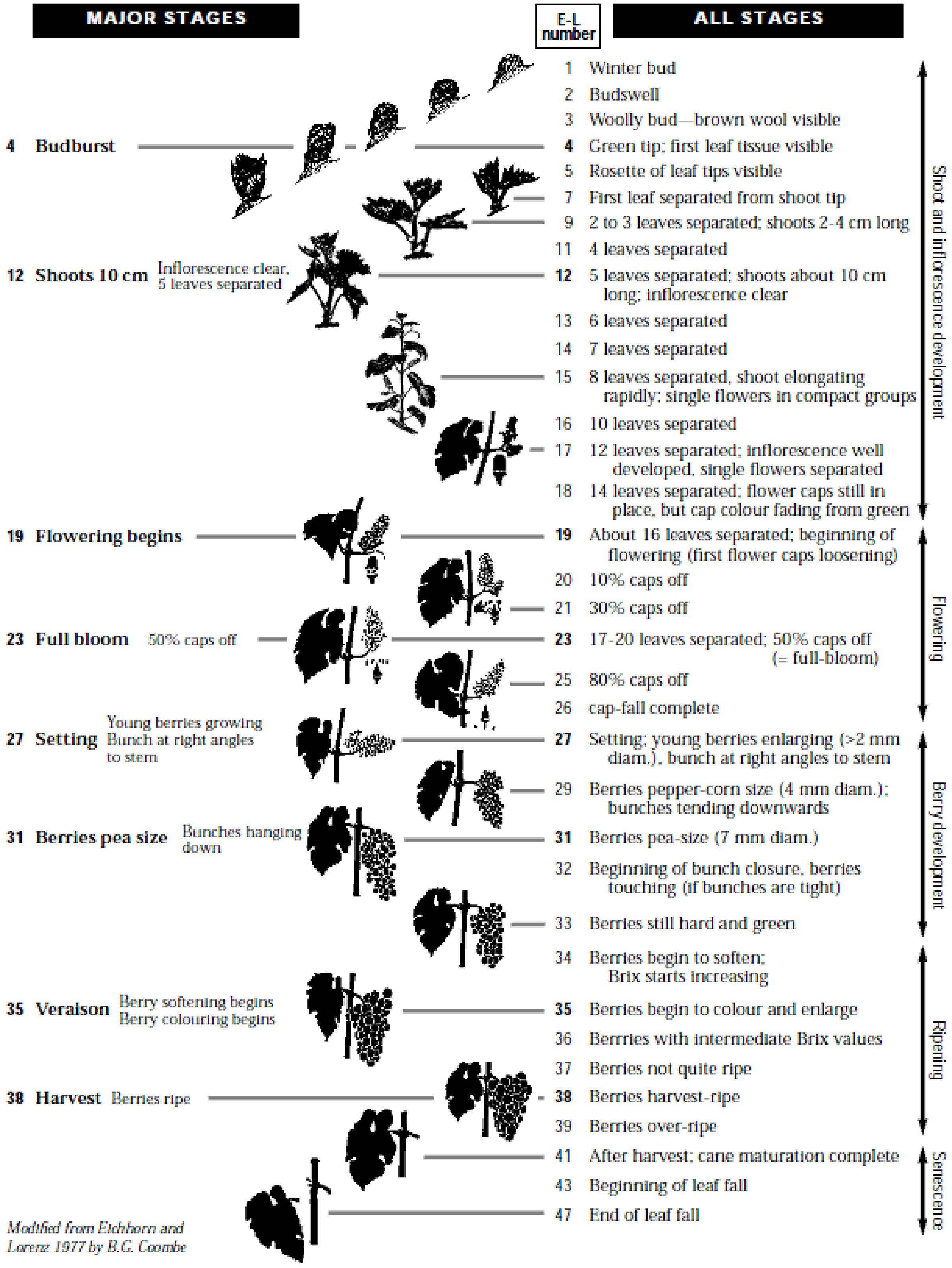
This reasearch has laid the foundation for future research projects that could provide a more clear insight as to how groundcovers compete with neighboring grapevines for water and nutrients. The results from this work clearly showcase the negative effects that planting groundcovers along with newly planted vines has on the vine growth and yield. More research is necessary to determine when the optimal time for groundcover planting. Planting groundcovers in the second and third year of vine growth would help determine if it’s necessary for the vines to grow unincumbered for a year or two. Results from this research indicated that there is more than just water competition taking place between groundcovers and neighboring vines. A more in depth study looking at nutrient usage amongst the groundcovers and vines would also be beneficial. Finally, determining water stress thresholds for grapevines grown in the field, rather than in the greenhouse, would provide clear information that would be directly applicable to grape growers in the Midwest.

# APPENDICES

**APPENDIX A:** Satellite image of commercial vineyard and layout of groundcover plots.



## **APPENDIX B**. Modified Eichhorn and Lorenz Bud Growth Stages. Coombe (1995)



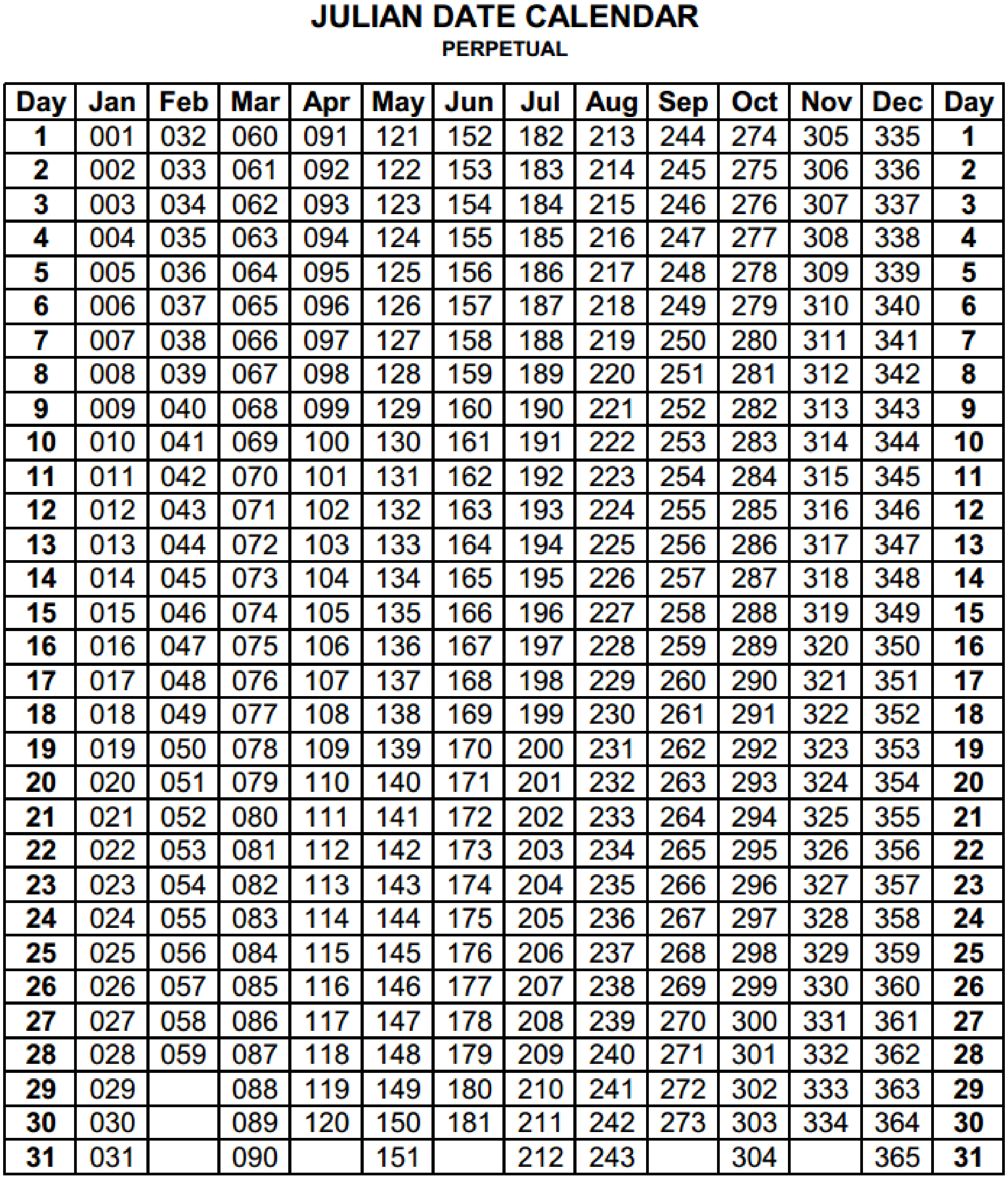
**MAJOR STAGES**

| | | |
|---|---|---|
| **4** | **Budburst** | |
| **12** | **Shoots 10 cm** | Inflorescence clear, 5 leaves separated |
| **19** | **Flowering begins** | |
| **23** | **Full bloom** | 50% caps off |
| **27** | **Setting** | Young berries growing Bunch at right angles to stem |
| **31** | **Berries pea size** | Bunches hanging down |
| **35** | **Veraison** | Berry softening begins Berry colouring begins |
| **38** | **Harvest** | Berries ripe |

| E-L number | ALL STAGES | |
|---|---|---|
| 1 | Winter bud | Shoot and inflorescence development |
| 2 | Budswell | |
| 3 | Woolly bud—brown wool visible | |
| **4** | Green tip; first leaf tissue visible | |
| 5 | Rosette of leaf tips visible | |
| 7 | First leaf separated from shoot tip | |
| 9 | 2 to 3 leaves separated; shoots 2-4 cm long | |
| 11 | 4 leaves separated | |
| **12** | 5 leaves separated; shoots about 10 cm long; inflorescence clear | |
| 13 | 6 leaves separated | |
| 14 | 7 leaves separated | |
| 15 | 8 leaves separated, shoot elongating rapidly; single flowers in compact groups | |
| 16 | 10 leaves separated | |
| 17 | 12 leaves separated; inflorescence well developed, single flowers separated | |
| 18 | 14 leaves separated; flower caps still in place, but cap colour fading from green | |
| **19** | About 16 leaves separated; beginning of flowering (first flower caps loosening) | Flowering |
| 20 | 10% caps off | |
| 21 | 30% caps off | |
| **23** | 17-20 leaves separated; 50% caps off (= full-bloom) | |
| 25 | 80% caps off | |
| 26 | cap-fall complete | |
| **27** | Setting; young berries enlarging (>2 mm diam.), bunch at right angles to stem | Berry development |
| 29 | Berries pepper-corn size (4 mm diam.); bunches tending downwards | |
| **31** | Berries pea-size (7 mm diam.) | |
| 32 | Beginning of bunch closure, berries touching (if bunches are tight) | |
| 33 | Berries still hard and green | |
| 34 | Berries begin to soften; Brix starts increasing | Ripening |
| **35** | Berries begin to colour and enlarge | |
| 36 | Berrries with intermediate Brix values | |
| 37 | Berries not quite ripe | |
| **38** | Berries harvest-ripe | |
| 39 | Berries over-ripe | |
| 41 | After harvest; cane maturation complete | Senescence |
| 43 | Beginning of leaf fall | |
| 47 | End of leaf fall | |

*Modified from Eichhorn and Lorenz 1977 by B.G. Coombe*

## **APPENDIX C.** Julian Date Calendar



**JULIAN DATE CALENDAR**

**PERPETUAL**

| Day | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Day |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 001 | 032 | 060 | 091 | 121 | 152 | 182 | 213 | 244 | 274 | 305 | 335 | **1** |
| **2** | 002 | 033 | 061 | 092 | 122 | 153 | 183 | 214 | 245 | 275 | 306 | 336 | **2** |
| **3** | 003 | 034 | 062 | 093 | 123 | 154 | 184 | 215 | 246 | 276 | 307 | 337 | **3** |
| **4** | 004 | 035 | 063 | 094 | 124 | 155 | 185 | 216 | 247 | 277 | 308 | 338 | **4** |
| **5** | 005 | 036 | 064 | 095 | 125 | 156 | 186 | 217 | 248 | 278 | 309 | 339 | **5** |
| **6** | 006 | 037 | 065 | 096 | 126 | 157 | 187 | 218 | 249 | 279 | 310 | 340 | **6** |
| **7** | 007 | 038 | 066 | 097 | 127 | 158 | 188 | 219 | 250 | 280 | 311 | 341 | **7** |
| **8** | 008 | 039 | 067 | 098 | 128 | 159 | 189 | 220 | 251 | 281 | 312 | 342 | **8** |
| **9** | 009 | 040 | 068 | 099 | 129 | 160 | 190 | 221 | 252 | 282 | 313 | 343 | **9** |
| **10** | 010 | 041 | 069 | 100 | 130 | 161 | 191 | 222 | 253 | 283 | 314 | 344 | **10** |
| **11** | 011 | 042 | 070 | 101 | 131 | 162 | 192 | 223 | 254 | 284 | 315 | 345 | **11** |
| **12** | 012 | 043 | 071 | 102 | 132 | 163 | 193 | 224 | 255 | 285 | 316 | 346 | **12** |
| **13** | 013 | 044 | 072 | 103 | 133 | 164 | 194 | 225 | 256 | 286 | 317 | 347 | **13** |
| **14** | 014 | 045 | 073 | 104 | 134 | 165 | 195 | 226 | 257 | 287 | 318 | 348 | **14** |
| **15** | 015 | 046 | 074 | 105 | 135 | 166 | 196 | 227 | 258 | 288 | 319 | 349 | **15** |
| **16** | 016 | 047 | 075 | 106 | 136 | 167 | 197 | 228 | 259 | 289 | 320 | 350 | **16** |
| **17** | 017 | 048 | 076 | 107 | 137 | 168 | 198 | 229 | 260 | 290 | 321 | 351 | **17** |
| **18** | 018 | 049 | 077 | 108 | 138 | 169 | 199 | 230 | 261 | 291 | 322 | 352 | **18** |
| **19** | 019 | 050 | 078 | 109 | 139 | 170 | 200 | 231 | 262 | 292 | 323 | 353 | **19** |
| **20** | 020 | 051 | 079 | 110 | 140 | 171 | 201 | 232 | 263 | 293 | 324 | 354 | **20** |
| **21** | 021 | 052 | 080 | 111 | 141 | 172 | 202 | 233 | 264 | 294 | 325 | 355 | **21** |
| **22** | 022 | 053 | 081 | 112 | 142 | 173 | 203 | 234 | 265 | 295 | 326 | 356 | **22** |
| **23** | 023 | 054 | 082 | 113 | 143 | 174 | 204 | 235 | 266 | 296 | 327 | 357 | **23** |
| **24** | 024 | 055 | 083 | 114 | 144 | 175 | 205 | 236 | 267 | 297 | 328 | 358 | **24** |
| **25** | 025 | 056 | 084 | 115 | 145 | 176 | 206 | 237 | 268 | 298 | 329 | 359 | **25** |
| **26** | 026 | 057 | 085 | 116 | 146 | 177 | 207 | 238 | 269 | 299 | 330 | 360 | **26** |
| **27** | 027 | 058 | 086 | 117 | 147 | 178 | 208 | 239 | 270 | 300 | 331 | 361 | **27** |
| **28** | 028 | 059 | 087 | 118 | 148 | 179 | 209 | 240 | 271 | 301 | 332 | 362 | **28** |
| **29** | 029 |  | 088 | 119 | 149 | 180 | 210 | 241 | 272 | 302 | 333 | 363 | **29** |
| **30** | 030 |  | 089 | 120 | 150 | 181 | 211 | 242 | 273 | 303 | 334 | 364 | **30** |
| **31** | 031 |  | 090 |  | 151 |  | 212 | 243 |  | 304 |  | 365 | **31** |

**APPENDIX D.** Grapevine shoot length - 2014

| Treatment | Plant # | 29-Jul | 5-Aug | 12-Aug | 19-Aug | Final Length |
|---|---|---|---|---|---|---|
| **T1-A** | **1** | 69 | 75 | 85 | 89 | |
| **T1-A** | **2** | 50 | 53 | 57 | 59 | 74 |
| **T1-B** | **1** | 56 | 60 | 65 | 70 | |
| **T1-B** | **2** | 44 | 52 | 58 | 60 | 65 |
| **T1-C** | **1** | 42 | 48 | 52 | 55 | |
| **T1-C** | **2** | 49 | 57 | 65 | 74 | 64.5 |
| **T1-D** | **1** | 57 | 57 | 59 | 61 | |
| **T1-D** | **2** | 48 | 52 | 56 | 59 | 60 |
| **T1-E** | **1** | 38 | 43 | 46 | 49 | |
| **T1-E** | **2** | 39 | 41 | 42 | 43 | 46 |
| **T2-A** | **1** | 52 | 60 | 71 | 86 | |
| **T2-A** | **2** | 43 | 54 | 66 | 76 | 81 |
| **T2-B** | **1** | 57 | 62 | 66 | 68 | |
| **T2-B** | **2** | 50 | 54 | 57 | 59 | 63.5 |
| **T2-C** | **1** | 50 | 52 | 54 | 55 | |
| **T2-C** | **2** | 53 | 59 | 64 | 65 | 60 |
| **T2-D** | **1** | 45 | 49 | 51 | 53 | |
| **T2-D** | **2** | 41 | 43 | 44 | 45 | 49 |
| **T2-E** | **1** | 37 | 47 | 54 | 62 | |
| **T2-E** | **2** | 44 | 50 | 52 | 54 | 58 |
| **T3-A** | **1** | 58 | 62 | 65 | 68 | |
| **T3-A** | **2** | 48 | 55 | 62 | 69 | 68.5 |
| **T3-B** | **1** | 45 | 46 | 48 | 47 | |
| **T3-B** | **2** | 35 | 40 | 46 | 50 | 48.5 |
| **T3-C** | **1** | 43 | 43 | 44 | 47 | |
| **T3-C** | **2** | 48 | 48 | 49 | 50 | 48.5 |
| **T3-D** | **1** | 37 | 40 | 42 | 46 | |
| **T3-D** | **2** | 37 | 40 | 41 | 43 | 44.5 |
| **T3-E** | **1** | 49 | 50 | 50 | 51 | |
| **T3-E** | **2** | 39 | 41 | 44 | 47 | 49 |
| **T4-A** | **1** | 48 | 51 | 61 | 72 | |
| **T4-A** | **2** | 47 | 57 | 64 | 70 | 71 |
| **T4-B** | **1** | 48 | 54 | 61 | 70 | |
| **T4-B** | **2** | 43 | 51 | 58 | 67 | 68.5 |
| **T4-C** | **1** | 65 | 68 | 68 | 69 | |
| **T4-C** | **2** | 65 | 68 | 68 | 69 | 69 |
| **T4-D** | **1** | 76 | 83 | 87 | 95 | |
| **T4-D** | **2** | 60 | 68 | 73 | 80 | 87.5 |
| **T4-E** | **1** | 64 | 69 | 75 | 90 | |
| **T4-E** | **2** | 54 | 61 | 65 | 71 | 80.5 |
| **T6-A** | **1** | 72 | 72 | 78 | 84 | |
| **T6-A** | **2** | 45 | 52 | 53 | 54 | 69 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **T6-B** | **1** | 63 | 73 | 80 | 89 | |
| **T6-B** | **2** | . | . | . | . | 89 |
| **T6-C** | **1** | 57 | 60 | 62 | 67 | |
| **T6-C** | **2** | 54 | 67 | 79 | 97 | 82 |
| **T6-D** | **1** | 57 | 67 | 70 | 79 | |
| **T6-D** | **2** | 54 | 60 | 64 | 66 | 72.5 |
| **T6-E** | **1** | 52 | 57 | 61 | 67 | |
| **T6-E** | **2** | 41 | 45 | 50 | 55 | 61 |

**APPENDIX E**: 2014 Vegetation Fraction Data

| Date | Treatment | Veg Fraction | | Date | Treatment | Veg Fraction |
|---|---|---|---|---|---|---|
| 7/11/2014 | T1-A | 0.057300422 | | 7/29/2014 | T3-B | 0.896746627 |
| 7/11/2014 | T1-B | 0.117677486 | | 7/29/2014 | T3-C | 0.805815983 |
| 7/11/2014 | T1-C | 0.045244407 | | 7/29/2014 | T3-D | 0.354029269 |
| 7/11/2014 | T1-D | 0.124682098 | | 7/29/2014 | T3-E | 0.640229644 |
| 7/11/2014 | T1-E | 0.132521876 | | 8/5/2014 | T3-A | 0.99266671 |
| 7/15/2014 | T1-A | 0.106548235 | | 8/5/2014 | T3-B | 0.978644015 |
| 7/15/2014 | T1-B | 0.296227747 | | 8/5/2014 | T3-C | 0.922744515 |
| 7/15/2014 | T1-C | 0.084944394 | | 8/5/2014 | T3-D | 0.520372645 |
| 7/15/2014 | T1-D | 0.218460386 | | 8/5/2014 | T3-E | 0.832253007 |
| 7/15/2014 | T1-E | 0.182063343 | | 8/12/2014 | T3-A | 0.957562826 |
| 7/22/2014 | T1-A | 0.243946399 | | 8/12/2014 | T3-B | 0.993157033 |
| 7/22/2014 | T1-B | 0.625773201 | | 8/12/2014 | T3-C | 0.919859153 |
| 7/22/2014 | T1-C | 0.280866093 | | 8/12/2014 | T3-D | 0.592541704 |
| 7/22/2014 | T1-D | 0.485721367 | | 8/12/2014 | T3-E | 0.882414113 |
| 7/22/2014 | T1-E | 0.380366611 | | 8/19/2014 | T3-A | 0.963535605 |
| 7/29/2014 | T1-A | 0.331665697 | | 8/19/2014 | T3-B | 0.995937325 |
| 7/29/2014 | T1-B | 0.8274306 | | 8/19/2014 | T3-C | 0.984500948 |
| 7/29/2014 | T1-C | 0.436742963 | | 8/19/2014 | T3-D | 0.842272296 |
| 7/29/2014 | T1-D | 0.49452832 | | 8/19/2014 | T3-E | 0.973719234 |
| 7/29/2014 | T1-E | 0.43037146 | | | | |
| 8/5/2014 | T1-A | 0.558687874 | | 7/11/2014 | T5-A | 0 |
| 8/5/2014 | T1-B | 0.947680935 | | 7/11/2014 | T5-B | 0.162709061 |
| 8/5/2014 | T1-C | 0.767371438 | | 7/11/2014 | T5-C | 0.007071964 |
| 8/5/2014 | T1-D | 0.728547028 | | 7/11/2014 | T5-D | 0.18623917 |
| 8/5/2014 | T1-E | 0.631034743 | | 7/11/2014 | T5-E | 0.517549248 |
| 8/12/2014 | T1-A | 0.591841243 | | 7/15/2014 | T5-A | 5.39E-06 |
| 8/12/2014 | T1-B | 0.981876913 | | 7/15/2014 | T5-B | 0.159697077 |
| 8/12/2014 | T1-C | 0.942467887 | | 7/15/2014 | T5-C | 0.007635027 |
| 8/12/2014 | T1-D | 0.929533601 | | 7/15/2014 | T5-D | 0.155596685 |
| 8/12/2014 | T1-E | 0.688512975 | | 7/15/2014 | T5-E | 0.567758847 |
| 8/19/2014 | T1-A | 0.735427712 | | 7/22/2014 | T5-A | 0 |
| 8/19/2014 | T1-B | 0.997949804 | | 7/22/2014 | T5-B | 0.271541877 |
| 8/19/2014 | T1-C | 0.977124553 | | 7/22/2014 | T5-C | 0.011395965 |
| 8/19/2014 | T1-D | 0.997386741 | | 7/22/2014 | T5-D | 0.18757274 |
| 8/19/2014 | T1-E | 0.851372904 | | 7/22/2014 | T5-E | 0.784209449 |
| | | | | 7/29/2014 | T5-A | 3.50E-05 |
| 7/11/2014 | T2-A | 0.002365404 | | 7/29/2014 | T5-B | 0.240339023 |
| 7/11/2014 | T2-B | 0.134574766 | | 7/29/2014 | T5-C | 0.007276715 |
| 7/11/2014 | T2-C | 0.243733566 | | 7/29/2014 | T5-D | 0.132740097 |
| 7/11/2014 | T2-D | 0.223659964 | | 7/29/2014 | T5-E | 0.92231885 |
| 7/11/2014 | T2-E | 0.007066576 | | 8/5/2014 | T5-A | 0.002551295 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 7/15/2014 | T2-A | 0.014143929 | | 8/5/2014 | T5-B | 0.429972736 |
| 7/15/2014 | T2-B | 0.326916031 | | 8/5/2014 | T5-C | 0.018960947 |
| 7/15/2014 | T2-C | 0.434921764 | | 8/5/2014 | T5-D | 0.305640868 |
| 7/15/2014 | T2-D | 0.493908681 | | 8/5/2014 | T5-E | 0.9669975 |
| 7/15/2014 | T2-E | 0.030987327 | | 8/12/2014 | T5-A | 0.007228221 |
| 7/22/2014 | T2-A | 0.048210591 | | 8/12/2014 | T5-B | 0.428235053 |
| 7/22/2014 | T2-B | 0.814086814 | | 8/12/2014 | T5-C | 0.021719686 |
| 7/22/2014 | T2-C | 0.766743717 | | 8/12/2014 | T5-D | 0.304633282 |
| 7/22/2014 | T2-D | 0.782668434 | | 8/12/2014 | T5-E | 0.962525324 |
| 7/22/2014 | T2-E | 0.100758653 | | 8/19/2014 | T5-A | 0.022107634 |
| 7/29/2014 | T2-A | 0.190759839 | | 8/19/2014 | T5-B | 0.482949157 |
| 7/29/2014 | T2-B | 0.849018277 | | 8/19/2014 | T5-C | 0.081625286 |
| 7/29/2014 | T2-C | 0.770456162 | | 8/19/2014 | T5-D | 0.40206205 |
| 7/29/2014 | T2-D | 0.827519505 | | 8/19/2014 | T5-E | 0.995355403 |
| 7/29/2014 | T2-E | 0.230009914 | | | | |
| 8/5/2014 | T2-A | 0.503513082 | | 7/11/2014 | T6-A | 0.021218587 |
| 8/5/2014 | T2-B | 0.908934652 | | 7/11/2014 | T6-B | 0.003766326 |
| 8/5/2014 | T2-C | 0.922073689 | | 7/11/2014 | T6-C | 0.132756261 |
| 8/5/2014 | T2-D | 0.950614789 | | 7/11/2014 | T6-D | 0.007152787 |
| 8/5/2014 | T2-E | 0.771242834 | | 7/11/2014 | T6-E | 0.344449114 |
| 8/12/2014 | T2-A | 0.626155761 | | 7/15/2014 | T6-A | 0.007890965 |
| 8/12/2014 | T2-B | 0.844559572 | | 7/15/2014 | T6-B | 0.005019074 |
| 8/12/2014 | T2-C | 0.918202293 | | 7/15/2014 | T6-C | 0.108609207 |
| 8/12/2014 | T2-D | 0.748644877 | | 7/15/2014 | T6-D | 0.01815811 |
| 8/12/2014 | T2-E | 0.839607849 | | 7/15/2014 | T6-E | 0.346202961 |
| 8/19/2014 | T2-A | 0.840224794 | | 7/22/2014 | T6-A | 0.01544517 |
| 8/19/2014 | T2-B | 0.919985775 | | 7/22/2014 | T6-B | 0.038934868 |
| 8/19/2014 | T2-C | 0.944474977 | | 7/22/2014 | T6-C | 0.225238696 |
| 8/19/2014 | T2-D | 0.931756218 | | 7/22/2014 | T6-D | 0.031038515 |
| 8/19/2014 | T2-E | 0.917544937 | | 7/22/2014 | T6-E | 0.440234493 |
| | | | | 7/29/2014 | T6-A | 0.036968188 |
| 7/11/2014 | T3-A | 0.115465645 | | 7/29/2014 | T6-B | 0.122254731 |
| 7/11/2014 | T3-B | 0.224575952 | | 7/29/2014 | T6-C | 0.302927928 |
| 7/11/2014 | T3-C | 0.262875016 | | 7/29/2014 | T6-D | 0.052033493 |
| 7/11/2014 | T3-D | 0.165521682 | | 7/29/2014 | T6-E | 0.486303289 |
| 7/11/2014 | T3-E | 0.461135178 | | 8/5/2014 | T6-A | 0.06977402 |
| 7/15/2014 | T3-A | 0.258874305 | | 8/5/2014 | T6-B | 0.229255571 |
| 7/15/2014 | T3-B | 0.41124348 | | 8/5/2014 | T6-C | 0.471531639 |
| 7/15/2014 | T3-C | 0.423323742 | | 8/5/2014 | T6-D | 0.10864423 |
| 7/15/2014 | T3-D | 0.163840575 | | 8/5/2014 | T6-E | 0.572823721 |
| 7/15/2014 | T3-E | 0.563186991 | | 8/12/2014 | T6-A | 0.000309819 |
| 7/22/2014 | T3-A | 0.451239816 | | 8/12/2014 | T6-B | 0.240077697 |
| 7/22/2014 | T3-B | 0.797793008 | | 8/12/2014 | T6-C | 0.496241756 |
| 7/22/2014 | T3-C | 0.759968102 | | 8/12/2014 | T6-D | 0.167264753 |
| 7/22/2014 | T3-D | 0.312720915 | | 8/12/2014 | T6-E | 0.493682379 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 7/22/2014 | T3-E | 0.703254989 | | 8/19/2014 | T6-A | 0.000220915 |
| 7/29/2014 | T3-A | 0.625414889 | | 8/19/2014 | T6-B | 0.224538234 |
| | | | | 8/19/2014 | T6-C | 0.674573796 |
| | | | | 8/19/2014 | T6-D | 0.265000647 |
| | | | | 8/19/2014 | T6-E | 0.482539657 |

**APPENDIX F.** 2014 Alleyway Vegetation Fraction Data

| Date | Treatment | Veg Fraction | | Date | Treatment | Veg Fraction |
|---|---|---|---|---|---|---|
| 7/11/2014 | T1-A | 0.037528557 | | 7/29/2014 | T3-C | 0.772880835 |
| 7/11/2014 | T1-B | 0.218231389 | | 7/29/2014 | T3-D | 0.202163886 |
| 7/11/2014 | T1-C | 0.262419716 | | 7/29/2014 | T5-A | 0 |
| 7/11/2014 | T1-D | 0.265237726 | | 7/29/2014 | T5-B | 0.341359003 |
| 7/11/2014 | T1-E | 0.180231368 | | 7/29/2014 | T5-C | 0.108205095 |
| 7/11/2014 | T2-A | 0.002718328 | | 7/29/2014 | T5-D | 0.297254192 |
| 7/11/2014 | T2-B | 0.058811802 | | 7/29/2014 | T5-E | 0.183873766 |
| 7/11/2014 | T2-C | 0.009968102 | | 7/29/2014 | T6-A | 0.012883098 |
| 7/11/2014 | T2-D | 0.045820941 | | 7/29/2014 | T6-B | 0.266789517 |
| 7/11/2014 | T2-E | 0.041750183 | | 7/29/2014 | T6-C | 0.404322385 |
| 7/11/2014 | T3-A | 0.049269365 | | 7/29/2014 | T6-D | 0.207269171 |
| 7/11/2014 | T3-B | 0.17396224 | | 7/29/2014 | T6-E | 0.038894457 |
| 7/11/2014 | T3-C | 0.321603302 | | 8/5/2014 | T1-A | 0.475332988 |
| 7/11/2014 | T3-D | 0.018492176 | | 8/5/2014 | T1-B | 0.970984741 |
| 7/11/2014 | T3-E | 0.380385469 | | 8/5/2014 | T1-C | 0.995711022 |
| 7/11/2014 | T5-A | 0 | | 8/5/2014 | T1-D | 0.977534053 |
| 7/11/2014 | T5-B | 0.12485452 | | 8/5/2014 | T1-E | 0.495024031 |
| 7/11/2014 | T5-C | 0.011695008 | | 8/5/2014 | T2-A | 0.757117764 |
| 7/11/2014 | T5-D | 0.148575908 | | 8/5/2014 | T2-B | 0.796327428 |
| 7/11/2014 | T5-E | 0.441576146 | | 8/5/2014 | T2-C | 0.450302276 |
| 7/11/2014 | T6-A | 0.038999526 | | 8/5/2014 | T2-D | 0.906224406 |
| 7/11/2014 | T6-B | 0.064350834 | | 8/5/2014 | T2-E | 0.706240032 |
| 7/11/2014 | T6-C | 0.002020561 | | 8/5/2014 | T3- E | 0.934439523 |
| 7/11/2014 | T6-D | 0.061282275 | | 8/5/2014 | T3-A | 0.728476982 |
| 7/11/2014 | T6-E | 0.001842752 | | 8/5/2014 | T3-B | 0.881390362 |
| 7/15/2014 | T1-A | 0.066217833 | | 8/5/2014 | T3-C | 0.913757058 |
| 7/15/2014 | T1-B | 0.409656666 | | 8/5/2014 | T3-D | 0.344904414 |
| 7/15/2014 | T1-C | 0.464395017 | | 8/5/2014 | T5-A | 0.000113151 |
| 7/15/2014 | T1-D | 0.386032264 | | 8/5/2014 | T5-B | 0.483431398 |
| 7/15/2014 | T1-E | 0.256678628 | | 8/5/2014 | T5-C | 0.229269042 |
| 7/15/2014 | T2-A | 0.028964072 | | 8/5/2014 | T5-D | 0.690687099 |
| 7/15/2014 | T2-B | 0.222916397 | | 8/5/2014 | T5-E | 0.355327816 |
| 7/15/2014 | T2-C | 0.02302901 | | 8/5/2014 | T6-A | 0.036391655 |
| 7/15/2014 | T2-D | 0.100252166 | | 8/5/2014 | T6-B | 0.338153045 |
| 7/15/2014 | T2-E | 0.074873917 | | 8/5/2014 | T6-C | 0.721159856 |
| 7/15/2014 | T3- E | 0.559035411 | | 8/5/2014 | T6-D | 0.426785637 |
| 7/15/2014 | T3-A | 0.092315402 | | 8/5/2014 | T6-E | 0.149529613 |
| 7/15/2014 | T3-B | 0.278040002 | | 8/12/2014 | T1-A | 0.538878292 |
| 7/15/2014 | T3-C | 0.519761089 | | 8/12/2014 | T1-B | 0.985990775 |
| 7/15/2014 | T3-D | 0.072174447 | | 8/12/2014 | T1-C | 0.971469675 |
| 7/15/2014 | T5-A | 0 | | 8/12/2014 | T1-D | 0.992704427 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 7/15/2014 | T5-B | 0.145682465 | | 8/12/2014 | T1-E | 0.528972154 |
| 7/15/2014 | T5-C | 0.023586685 | | 8/12/2014 | T2-A | 0.665570175 |
| 7/15/2014 | T5-D | 0.027304517 | | 8/12/2014 | T2-B | 0.772791931 |
| 7/15/2014 | T5-E | 0.032792362 | | 8/12/2014 | T2-C | 0.552542674 |
| 7/15/2014 | T6-A | 0 | | 8/12/2014 | T2-D | 0.695067675 |
| 7/15/2014 | T6-B | 0.067858528 | | 8/12/2014 | T2-E | 0.507497629 |
| 7/15/2014 | T6-C | 0.070372107 | | 8/12/2014 | T3- E | 0.951886396 |
| 7/15/2014 | T6-D | 0.04324001 | | 8/12/2014 | T3-A | 0.793129553 |
| 7/15/2014 | T6-E | 0.000748955 | | 8/12/2014 | T3-B | 0.944146299 |
| 7/22/2014 | T1-A | 0.163996832 | | 8/12/2014 | T3-C | 0.943995431 |
| 7/22/2014 | T1-B | 0.72142657 | | 8/12/2014 | T3-D | 0.48166408 |
| 7/22/2014 | T1-C | 0.884081749 | | 8/12/2014 | T5-A | 0.000651968 |
| 7/22/2014 | T1-D | 0.720041812 | | 8/12/2014 | T5-B | 0.430735161 |
| 7/22/2014 | T1-E | 0.456374736 | | 8/12/2014 | T5-C | 0.276173003 |
| 7/22/2014 | T2-A | 0.147562934 | | 8/12/2014 | T5-D | 0.78966227 |
| 7/22/2014 | T2-B | 0.554199534 | | 8/12/2014 | T5-E | 0.287331889 |
| 7/22/2014 | T2-C | 0.184482629 | | 8/12/2014 | T6-A | 0.020518126 |
| 7/22/2014 | T2-D | 0.46614617 | | 8/12/2014 | T6-B | 0.370740657 |
| 7/22/2014 | T2-E | 0.17925611 | | 8/12/2014 | T6-C | 0.837180482 |
| 7/22/2014 | T3- E | 0.836444998 | | 8/12/2014 | T6-D | 0.159686301 |
| 7/22/2014 | T3-A | 0.187276391 | | 8/12/2014 | T6-E | 0.253464589 |
| 7/22/2014 | T3-B | 0.445778913 | | 8/19/2014 | T1-A | 0.825102914 |
| 7/22/2014 | T3-C | 0.766353076 | | 8/19/2014 | T1-B | 0.990185461 |
| 7/22/2014 | T3-D | 0.166117074 | | 8/19/2014 | T1-C | 0.979112785 |
| 7/22/2014 | T5-A | 0 | | 8/19/2014 | T1-D | 0.996379154 |
| 7/22/2014 | T5-B | 0.260331803 | | 8/19/2014 | T1-E | 0.669069787 |
| 7/22/2014 | T5-C | 0.089381547 | | 8/19/2014 | T2-A | 0.725653584 |
| 7/22/2014 | T5-D | 0.183555864 | | 8/19/2014 | T2-B | 0.976453726 |
| 7/22/2014 | T5-E | 0.08447293 | | 8/19/2014 | T2-C | 0.751161149 |
| 7/22/2014 | T6-A | 0 | | 8/19/2014 | T2-D | 0.848727316 |
| 7/22/2014 | T6-B | 0.160039226 | | 8/19/2014 | T2-E | 0.684967563 |
| 7/22/2014 | T6-C | 0.290928488 | | 8/19/2014 | T3- E | 0.988043666 |
| 7/22/2014 | T6-D | 0.179107936 | | 8/19/2014 | T3-A | 0.966873572 |
| 7/22/2014 | T6-E | 0.019451269 | | 8/19/2014 | T3-B | 0.978716755 |
| 7/29/2014 | T1-A | 0.190937648 | | 8/19/2014 | T3-C | 0.980327816 |
| 7/29/2014 | T1-B | 0.846547804 | | 8/19/2014 | T3-D | 0.752599789 |
| 7/29/2014 | T1-C | 0.975219837 | | 8/19/2014 | T5-A | 0.00038256 |
| 7/29/2014 | T1-D | 0.880827299 | | 8/19/2014 | T5-B | 0.695862429 |
| 7/29/2014 | T1-E | 0.312567352 | | 8/19/2014 | T5-C | 0.601976378 |
| 7/29/2014 | T2-A | 0.268532588 | | 8/19/2014 | T5-D | 0.846957304 |
| 7/29/2014 | T2-B | 0.568782598 | | 8/19/2014 | T5-E | 0.415602504 |
| 7/29/2014 | T2-C | 0.235425018 | | 8/19/2014 | T6-A | 0.021237446 |
| 7/29/2014 | T2-D | 0.606823031 | | 8/19/2014 | T6-B | 0.609703004 |
| 7/29/2014 | T2-E | 0.26827665 | | 8/19/2014 | T6-C | 0.931026122 |
| 7/29/2014 | T3- E | 0.850944545 | | 8/19/2014 | T6-D | 0.3080844 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 7/29/2014 | T3-A | 0.340119725 | | 8/19/2014 | T6-E | 0.468320294 |
| 7/29/2014 | T3-B | 0.627228006 | | | | |

**APPENDIX G.** 2014 Pruning Weights (A.K.A total vine weight)

| Treatment | Plant # | Weight (lbs) | | Treatment | Plant # | Weight (lbs) |
|---|---|---|---|---|---|---|
| T1-A | 1 | 0.30 | | T6-A | 1 | 0.54 |
| T1-A | 2 | 0.08 | | T6-A | 2 | 0.18 |
| T1-B | 1 | 0.16 | | T6-B | 1 | 0.40 |
| T1-B | 2 | 0.08 | | T6-C | 1 | 0.16 |
| T1-C | 1 | 0.06 | | T6-C | 2 | 0.32 |
| T1-C | 2 | 0.10 | | T6-D | 1 | 0.40 |
| T1-D | 1 | 0.06 | | T6-D | 2 | 0.28 |
| T1-D | 2 | 0.04 | | T6-E | 1 | 0.22 |
| T1-E | 1 | 0.08 | | T6-E | 2 | 0.16 |
| T1-E | 2 | 0.04 | | | | |
| T2-A | 1 | 0.18 | | | | |
| T2-A | 2 | 0.16 | | | | |
| T2-B | 1 | 0.22 | | | | |
| T2-B | 2 | 0.12 | | | | |
| T2-C | 1 | 0.08 | | | | |
| T2-C | 2 | 0.16 | | | | |
| T2-D | 1 | 0.06 | | | | |
| T2-D | 2 | 0.06 | | | | |
| T2-E | 1 | 0.16 | | | | |
| T2-E | 2 | 0.06 | | | | |
| T3-A | 1 | 0.22 | | | | |
| T3-A | 2 | 0.20 | | | | |
| T3-B | 1 | 0.06 | | | | |
| T3-B | 2 | 0.06 | | | | |
| T3-C | 1 | 0.06 | | | | |
| T3-C | 2 | 0.04 | | | | |
| T3-D | 1 | 0.08 | | | | |
| T3-D | 2 | 0.02 | | | | |
| T3-E | 1 | 0.40 | | | | |
| T3-E | 2 | 0.08 | | | | |
| T4-A | 1 | 0.26 | | | | |
| T4-A | 2 | 0.20 | | | | |
| T4-B | 1 | 0.18 | | | | |
| T4-B | 2 | 0.16 | | | | |
| T4-C | 1 | 0.12 | | | | |
| T4-C | 2 | 0.10 | | | | |
| T4-D | 1 | 0.46 | | | | |
| T4-D | 2 | 0.38 | | | | |
| T4-E | 1 | 0.46 | | | | |
| T4-E | 2 | 0.14 | | | | |

**APPENDIX H.** 2015 Midday Leaf Water Potential Statistical Analyses

| Model Information | |
|---|---|
| **Data Set** | WORK.LWP |
| **Response Variable** | AvgWP |
| **Response Distribution** | Gaussian |
| **Link Function** | Identity |

| Class Level Information | | |
|---|---|---|
| **Class** | **Levels** | **Values** |
| **Block** | 5 | 1 2 3 4 5 |
| **Trt** | 5 | 1 2 3 4 6 |
| **Date** | 6 | 30JUN2015 07JUL2015 14JUL2015 29JUL2015 05AUG2015 12AUG2015 |
| **Rep** | 5 | E B A C D |

| | |
|---|---|
| **Number of Observations Read** | 150 |
| **Number of Observations Used** | 150 |

| Covariance Parameter Estimates | | | |
|---|---|---|---|
| **Cov Parm** | **Subject** | **Estimate** | **Standard Error** |
| **Block** | | 0.07485 | 0.08155 |
| **Block*Trt** | | 0 | . |
| **Var(1)** | **Block*Trt*Rep** | 2.2143 | 0.7220 |
| **Var(2)** | **Block*Trt*Rep** | 0.6009 | 0.2236 |
| **Var(3)** | **Block*Trt*Rep** | 0.6078 | 0.1945 |
| **Var(4)** | **Block*Trt*Rep** | 0.8913 | 0.2903 |
| **Var(5)** | **Block*Trt*Rep** | 1.0168 | 0.3803 |
| **Var(6)** | **Block*Trt*Rep** | 2.2049 | 0.7310 |
| **Rho(1)** | **Block*Trt*Rep** | 0.02033 | 0.2398 |

| Covariance Parameter Estimates | | | |
|---|---|---|---|
| **Cov Parm** | **Subject** | **Estimate** | **Standard Error** |
| **Rho(2)** | **Block*Trt*Rep** | 0.04452 | 0.2468 |
| **Rho(3)** | **Block*Trt*Rep** | -0.4722 | 0.1935 |
| **Rho(4)** | **Block*Trt*Rep** | -0.1886 | 0.2339 |
| **Rho(5)** | **Block*Trt*Rep** | 0.6188 | 0.1462 |

| Type III Tests of Fixed Effects | | | | |
|---|---|---|---|---|
| **Effect** | **Num DF** | **Den DF** | **F Value** | **Pr > F** |
| **Trt** | 4 | 14 | 1.99 | 0.1509 |
| **Date** | 5 | 102 | 353.59 | <.0001 |
| **Trt*Date** | 20 | 102 | 1.08 | 0.3860 |

| Trt*Date Least Squares Means | | | | | | |
|---|---|---|---|---|---|---|
| **Trt** | **Date** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** |
| **1** | **30JUN15** | -8.7600 | 0.6766 | 102 | -12.95 | <.0001 |
| **1** | **07JUL15** | -7.0000 | 0.3676 | 102 | -19.04 | <.0001 |
| **1** | **14JUL15** | -9.7800 | 0.3695 | 102 | -26.47 | <.0001 |
| **1** | **29JUL15** | -8.7800 | 0.4396 | 102 | -19.97 | <.0001 |
| **1** | **05AUG15** | -2.6000 | 0.4673 | 102 | -5.56 | <.0001 |
| **1** | **12AUG15** | -9.4200 | 0.6752 | 102 | -13.95 | <.0001 |
| **2** | **30JUN15** | -9.7144 | 0.6778 | 102 | -14.33 | <.0001 |
| **2** | **07JUL15** | -7.6044 | 0.3698 | 102 | -20.56 | <.0001 |
| **2** | **14JUL15** | -9.7244 | 0.3717 | 102 | -26.16 | <.0001 |
| **2** | **29JUL15** | -9.7444 | 0.4414 | 102 | -22.08 | <.0001 |
| **2** | **05AUG15** | -3.0644 | 0.4690 | 102 | -6.53 | <.0001 |
| **2** | **12AUG15** | -9.6844 | 0.6764 | 102 | -14.32 | <.0001 |
| **3** | **30JUN15** | -8.6956 | 0.6778 | 102 | -12.83 | <.0001 |

| Trt*Date Least Squares Means | | | | | | |
|---|---|---|---|---|---|---|
| **Trt** | **Date** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** |
| **3** | **07JUL15** | -6.8956 | 0.3698 | 102 | -18.65 | <.0001 |
| **3** | **14JUL15** | -10.0156 | 0.3717 | 102 | -26.95 | <.0001 |
| **3** | **29JUL15** | -10.5756 | 0.4414 | 102 | -23.96 | <.0001 |
| **3** | **05AUG15** | -3.0556 | 0.4690 | 102 | -6.52 | <.0001 |
| **3** | **12AUG15** | -9.2556 | 0.6764 | 102 | -13.68 | <.0001 |
| **4** | **30JUN15** | -7.6000 | 0.6766 | 102 | -11.23 | <.0001 |
| **4** | **07JUL15** | -6.9500 | 0.3676 | 102 | -18.90 | <.0001 |
| **4** | **14JUL15** | -9.5400 | 0.3695 | 102 | -25.82 | <.0001 |
| **4** | **29JUL15** | -9.8800 | 0.4396 | 102 | -22.48 | <.0001 |
| **4** | **05AUG15** | -2.3800 | 0.4673 | 102 | -5.09 | <.0001 |
| **4** | **12AUG15** | -8.5000 | 0.6752 | 102 | -12.59 | <.0001 |
| **6** | **30JUN15** | -8.0000 | 0.6766 | 102 | -11.82 | <.0001 |
| **6** | **07JUL15** | -6.7800 | 0.3676 | 102 | -18.44 | <.0001 |
| **6** | **14JUL15** | -10.3400 | 0.3695 | 102 | -27.98 | <.0001 |
| **6** | **29JUL15** | -10.2000 | 0.4396 | 102 | -23.20 | <.0001 |
| **6** | **05AUG15** | -2.5800 | 0.4673 | 102 | -5.52 | <.0001 |
| **6** | **12AUG15** | -9.5400 | 0.6752 | 102 | -14.13 | <.0001 |

| Simple Effect Comparisons of Trt*Date Least Squares Means By Date | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Simple Effect Level** | **Trt** | **Trt** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **Date 30JUN2015** | **1** | **2** | 0.9544 | 0.9420 | 102 | 1.01 | 0.3134 | 0.05 | -0.9140 | 2.8228 |
| **Date 30JUN2015** | **1** | **3** | -0.06441 | 0.9420 | 102 | -0.07 | 0.9456 | 0.05 | -1.9328 | 1.8040 |
| **Date 30JUN2015** | **1** | **4** | -1.1600 | 0.9411 | 102 | -1.23 | 0.2206 | 0.05 | -3.0267 | 0.7067 |

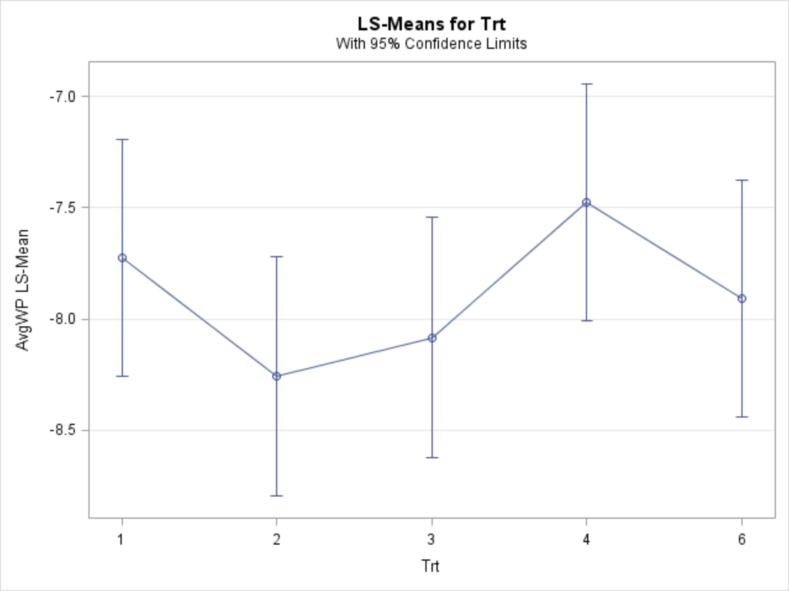
| Simple Effect Comparisons of Trt*Date Least Squares Means By Date | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Simple Effect Level** | **Trt** | **Trt** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **Date 30JUN2015** | **1** | **6** | -0.7600 | 0.9411 | 102 | -0.81 | 0.4212 | 0.05 | -2.6267 | 1.1067 |
| **Date 30JUN2015** | **2** | **3** | -1.0188 | 0.9445 | 102 | -1.08 | 0.2833 | 0.05 | -2.8923 | 0.8547 |
| **Date 30JUN2015** | **2** | **4** | -2.1144 | 0.9420 | 102 | -2.24 | 0.0270 | 0.05 | -3.9828 | -0.2460 |
| **Date 30JUN2015** | **2** | **6** | -1.7144 | 0.9420 | 102 | -1.82 | 0.0717 | 0.05 | -3.5828 | 0.1540 |
| **Date 30JUN2015** | **3** | **4** | -1.0956 | 0.9420 | 102 | -1.16 | 0.2475 | 0.05 | -2.9640 | 0.7728 |
| **Date 30JUN2015** | **3** | **6** | -0.6956 | 0.9420 | 102 | -0.74 | 0.4619 | 0.05 | -2.5640 | 1.1728 |
| **Date 30JUN2015** | **4** | **6** | 0.4000 | 0.9411 | 102 | 0.43 | 0.6717 | 0.05 | -1.4667 | 2.2667 |
| **Date 07JUL2015** | **1** | **2** | 0.6044 | 0.4919 | 102 | 1.23 | 0.2220 | 0.05 | -0.3713 | 1.5801 |
| **Date 07JUL2015** | **1** | **3** | -0.1044 | 0.4919 | 102 | -0.21 | 0.8323 | 0.05 | -1.0801 | 0.8713 |
| **Date 07JUL2015** | **1** | **4** | -0.05000 | 0.4903 | 102 | -0.10 | 0.9190 | 0.05 | -1.0225 | 0.9225 |
| **Date 07JUL2015** | **1** | **6** | -0.2200 | 0.4903 | 102 | -0.45 | 0.6546 | 0.05 | -1.1925 | 0.7525 |
| **Date 07JUL2015** | **2** | **3** | -0.7088 | 0.4968 | 102 | -1.43 | 0.1567 | 0.05 | -1.6942 | 0.2766 |
| **Date 07JUL2015** | **2** | **4** | -0.6544 | 0.4919 | 102 | -1.33 | 0.1864 | 0.05 | -1.6301 | 0.3213 |
| **Date 07JUL2015** | **2** | **6** | -0.8244 | 0.4919 | 102 | -1.68 | 0.0968 | 0.05 | -1.8001 | 0.1513 |
| **Date 07JUL2015** | **3** | **4** | 0.05441 | 0.4919 | 102 | 0.11 | 0.9121 | 0.05 | -0.9213 | 1.0301 |
| **Date 07JUL2015** | **3** | **6** | -0.1156 | 0.4919 | 102 | -0.23 | 0.8147 | 0.05 | -1.0913 | 0.8601 |

| Simple Effect Comparisons of Trt*Date Least Squares Means By Date | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Simple Effect Level** | **Trt** | **Trt** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **Date 07JUL2015** | **4** | **6** | -0.1700 | 0.4903 | 102 | -0.35 | 0.7295 | 0.05 | -1.1425 | 0.8025 |
| **Date 14JUL2015** | **1** | **2** | -0.05559 | 0.4947 | 102 | -0.11 | 0.9108 | 0.05 | -1.0368 | 0.9257 |
| **Date 14JUL2015** | **1** | **3** | 0.2356 | 0.4947 | 102 | 0.48 | 0.6349 | 0.05 | -0.7457 | 1.2168 |
| **Date 14JUL2015** | **1** | **4** | -0.2400 | 0.4931 | 102 | -0.49 | 0.6275 | 0.05 | -1.2180 | 0.7380 |
| **Date 14JUL2015** | **1** | **6** | 0.5600 | 0.4931 | 102 | 1.14 | 0.2587 | 0.05 | -0.4180 | 1.5380 |
| **Date 14JUL2015** | **2** | **3** | 0.2912 | 0.4996 | 102 | 0.58 | 0.5613 | 0.05 | -0.6997 | 1.2821 |
| **Date 14JUL2015** | **2** | **4** | -0.1844 | 0.4947 | 102 | -0.37 | 0.7101 | 0.05 | -1.1657 | 0.7968 |
| **Date 14JUL2015** | **2** | **6** | 0.6156 | 0.4947 | 102 | 1.24 | 0.2162 | 0.05 | -0.3657 | 1.5968 |
| **Date 14JUL2015** | **3** | **4** | -0.4756 | 0.4947 | 102 | -0.96 | 0.3386 | 0.05 | -1.4568 | 0.5057 |
| **Date 14JUL2015** | **3** | **6** | 0.3244 | 0.4947 | 102 | 0.66 | 0.5135 | 0.05 | -0.6568 | 1.3057 |
| **Date 14JUL2015** | **4** | **6** | 0.8000 | 0.4931 | 102 | 1.62 | 0.1078 | 0.05 | -0.1780 | 1.7780 |
| **Date 29JUL2015** | **1** | **2** | 0.9644 | 0.5984 | 102 | 1.61 | 0.1102 | 0.05 | -0.2226 | 2.1514 |
| **Date 29JUL2015** | **1** | **3** | 1.7956 | 0.5984 | 102 | 3.00 | 0.0034 | 0.05 | 0.6086 | 2.9826 |
| **Date 29JUL2015** | **1** | **4** | 1.1000 | 0.5971 | 102 | 1.84 | 0.0683 | 0.05 | -0.08433 | 2.2843 |
| **Date 29JUL2015** | **1** | **6** | 1.4200 | 0.5971 | 102 | 2.38 | 0.0193 | 0.05 | 0.2357 | 2.6043 |
| **Date 29JUL2015** | **2** | **3** | 0.8312 | 0.6025 | 102 | 1.38 | 0.1707 | 0.05 | -0.3638 | 2.0262 |

| Simple Effect Comparisons of Trt*Date Least Squares Means By Date | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Simple Effect Level** | **Trt** | **Trt** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **Date 29JUL2015** | **2** | **4** | 0.1356 | 0.5984 | 102 | 0.23 | 0.8212 | 0.05 | -1.0514 | 1.3226 |
| **Date 29JUL2015** | **2** | **6** | 0.4556 | 0.5984 | 102 | 0.76 | 0.4482 | 0.05 | -0.7314 | 1.6426 |
| **Date 29JUL2015** | **3** | **4** | -0.6956 | 0.5984 | 102 | -1.16 | 0.2478 | 0.05 | -1.8826 | 0.4914 |
| **Date 29JUL2015** | **3** | **6** | -0.3756 | 0.5984 | 102 | -0.63 | 0.5317 | 0.05 | -1.5626 | 0.8114 |
| **Date 29JUL2015** | **4** | **6** | 0.3200 | 0.5971 | 102 | 0.54 | 0.5932 | 0.05 | -0.8643 | 1.5043 |
| **Date 05AUG2015** | **1** | **2** | 0.4644 | 0.6390 | 102 | 0.73 | 0.4690 | 0.05 | -0.8031 | 1.7319 |
| **Date 05AUG2015** | **1** | **3** | 0.4556 | 0.6390 | 102 | 0.71 | 0.4775 | 0.05 | -0.8119 | 1.7231 |
| **Date 05AUG2015** | **1** | **4** | -0.2200 | 0.6378 | 102 | -0.34 | 0.7308 | 0.05 | -1.4850 | 1.0450 |
| **Date 05AUG2015** | **1** | **6** | -0.02000 | 0.6378 | 102 | -0.03 | 0.9750 | 0.05 | -1.2850 | 1.2450 |
| **Date 05AUG2015** | **2** | **3** | -0.00882 | 0.6428 | 102 | -0.01 | 0.9891 | 0.05 | -1.2838 | 1.2661 |
| **Date 05AUG2015** | **2** | **4** | -0.6844 | 0.6390 | 102 | -1.07 | 0.2867 | 0.05 | -1.9519 | 0.5831 |
| **Date 05AUG2015** | **2** | **6** | -0.4844 | 0.6390 | 102 | -0.76 | 0.4502 | 0.05 | -1.7519 | 0.7831 |
| **Date 05AUG2015** | **3** | **4** | -0.6756 | 0.6390 | 102 | -1.06 | 0.2929 | 0.05 | -1.9431 | 0.5919 |
| **Date 05AUG2015** | **3** | **6** | -0.4756 | 0.6390 | 102 | -0.74 | 0.4584 | 0.05 | -1.7431 | 0.7919 |
| **Date 05AUG2015** | **4** | **6** | 0.2000 | 0.6378 | 102 | 0.31 | 0.7545 | 0.05 | -1.0650 | 1.4650 |
| **Date 12AUG2015** | **1** | **2** | 0.2644 | 0.9400 | 102 | 0.28 | 0.7791 | 0.05 | -1.6001 | 2.1289 |

| Simple Effect Comparisons of Trt*Date Least Squares Means By Date | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Simple Effect Level** | **Trt** | **Trt** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **Date 12AUG2015** | **1** | **3** | -0.1644 | 0.9400 | 102 | -0.17 | 0.8615 | 0.05 | -2.0289 | 1.7001 |
| **Date 12AUG2015** | **1** | **4** | -0.9200 | 0.9391 | 102 | -0.98 | 0.3296 | 0.05 | -2.7828 | 0.9428 |
| **Date 12AUG2015** | **1** | **6** | 0.1200 | 0.9391 | 102 | 0.13 | 0.8986 | 0.05 | -1.7428 | 1.9828 |
| **Date 12AUG2015** | **2** | **3** | -0.4288 | 0.9426 | 102 | -0.45 | 0.6501 | 0.05 | -2.2984 | 1.4407 |
| **Date 12AUG2015** | **2** | **4** | -1.1844 | 0.9400 | 102 | -1.26 | 0.2105 | 0.05 | -3.0489 | 0.6801 |
| **Date 12AUG2015** | **2** | **6** | -0.1444 | 0.9400 | 102 | -0.15 | 0.8782 | 0.05 | -2.0089 | 1.7201 |
| **Date 12AUG2015** | **3** | **4** | -0.7556 | 0.9400 | 102 | -0.80 | 0.4234 | 0.05 | -2.6201 | 1.1089 |
| **Date 12AUG2015** | **3** | **6** | 0.2844 | 0.9400 | 102 | 0.30 | 0.7628 | 0.05 | -1.5801 | 2.1489 |
| **Date 12AUG2015** | **4** | **6** | 1.0400 | 0.9391 | 102 | 1.11 | 0.2707 | 0.05 | -0.8228 | 2.9028 |

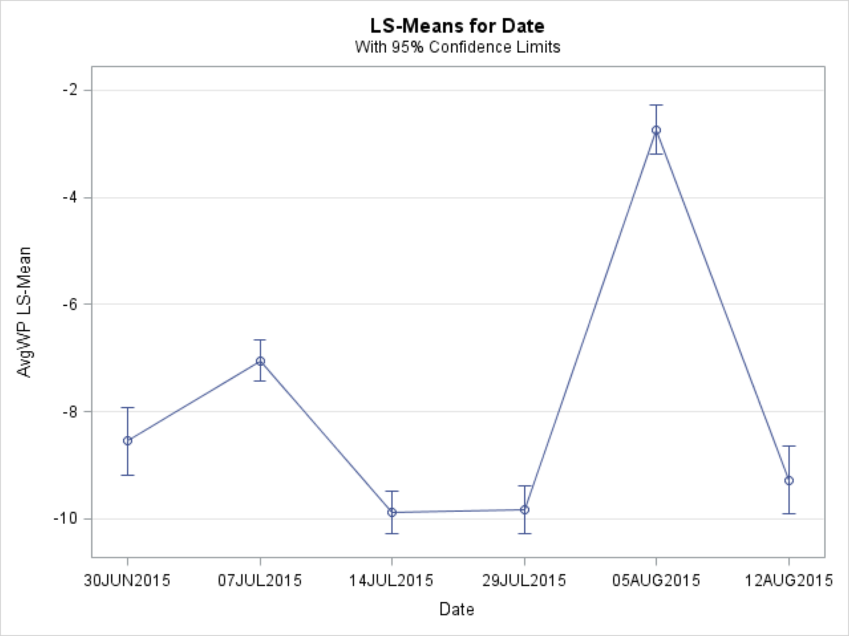
| Trt Least Squares Means | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Trt** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **1** | -7.7233 | 0.2478 | 14 | -31.17 | <.0001 | 0.05 | -8.2548 | -7.1919 |
| **2** | -8.2561 | 0.2510 | 14 | -32.89 | <.0001 | 0.05 | -8.7945 | -7.7177 |
| **3** | -8.0823 | 0.2510 | 14 | -32.20 | <.0001 | 0.05 | -8.6207 | -7.5438 |
| **4** | -7.4750 | 0.2478 | 14 | -30.17 | <.0001 | 0.05 | -8.0065 | -6.9435 |
| **6** | -7.9067 | 0.2478 | 14 | -31.91 | <.0001 | 0.05 | -8.4381 | -7.3752 |



| Differences of Trt Least Squares Means | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Trt** | **Trt** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **1** | **2** | 0.5327 | 0.3074 | 14 | 1.73 | 0.1050 | 0.05 | -0.1265 | 1.1920 |
| **1** | **3** | 0.3589 | 0.3074 | 14 | 1.17 | 0.2624 | 0.05 | -0.3004 | 1.0182 |
| **1** | **4** | -0.2483 | 0.3047 | 14 | -0.81 | 0.4288 | 0.05 | -0.9020 | 0.4053 |
| **1** | **6** | 0.1833 | 0.3047 | 14 | 0.60 | 0.5571 | 0.05 | -0.4703 | 0.8370 |
| **2** | **3** | -0.1738 | 0.3152 | 14 | -0.55 | 0.5900 | 0.05 | -0.8498 | 0.5021 |
| **2** | **4** | -0.7811 | 0.3074 | 14 | -2.54 | 0.0235 | 0.05 | -1.4404 | -0.1218 |
| **2** | **6** | -0.3494 | 0.3074 | 14 | -1.14 | 0.2747 | 0.05 | -1.0087 | 0.3099 |
| **3** | **4** | -0.6073 | 0.3074 | 14 | -1.98 | 0.0683 | 0.05 | -1.2665 | 0.05202 |
| **3** | **6** | -0.1756 | 0.3074 | 14 | -0.57 | 0.5769 | 0.05 | -0.8349 | 0.4837 |
| **4** | **6** | 0.4317 | 0.3047 | 14 | 1.42 | 0.1785 | 0.05 | -0.2220 | 1.0853 |

| Date Least Squares Means | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Date** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **30JUN15** | -8.5540 | 0.3218 | 102 | -26.58 | <.0001 | 0.05 | -9.1922 | -7.9158 |
| **07JUL15** | -7.0460 | 0.1975 | 102 | -35.68 | <.0001 | 0.05 | -7.4377 | -6.6543 |
| **14JUL15** | -9.8800 | 0.1982 | 102 | -49.85 | <.0001 | 0.05 | -10.2731 | -9.4869 |

| Date Least Squares Means | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Date | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper |
| **29JUL15** | -9.8360 | 0.2250 | 102 | -43.72 | <.0001 | 0.05 | -10.2823 | -9.3897 |
| **05AUG15** | -2.7360 | 0.2359 | 102 | -11.60 | <.0001 | 0.05 | -3.2039 | -2.2681 |
| **12AUG15** | -9.2800 | 0.3212 | 102 | -28.89 | <.0001 | 0.05 | -9.9171 | -8.6429 |



## **APPENDIX I.** 2016 Midday Leaf Water Potential Statistical Analyses

| Model Information | |
|---|---|
| **Data Set** | WORK.LWP |
| **Response Variable** | AvgWP |
| **Response Distribution** | Gaussian |
| **Link Function** | Identity |

| Class Level Information | | |
|---|---|---|
| **Class** | **Levels** | **Values** |
| **Block** | 5 | 1 2 3 4 5 |
| **Trt** | 5 | 1 2 3 4 6 |
| **Date** | 5 | 06JUL2016 12JUL2016 22JUL2016 01AUG2016 10AUG2016 |
| **Rep** | 5 | E B A C D |

| | |
|---|---|
| **Number of Observations Read** | 125 |
| **Number of Observations Used** | 125 |

| Covariance Parameter Estimates | | | |
|---|---|---|---|
| **Cov Parm** | **Subject** | **Estimate** | **Standard Error** |
| **Block** | | 0.03393 | 0.06512 |
| **Block*Trt** | | 0 | . |
| **Var(1)** | **Block*Trt*Rep** | 1.0700 | 0.3927 |
| **Var(2)** | **Block*Trt*Rep** | 0.3205 | 0.1298 |
| **Var(3)** | **Block*Trt*Rep** | 0.5020 | 0.1619 |
| **Var(4)** | **Block*Trt*Rep** | 1.1265 | 0.3831 |
| **Var(5)** | **Block*Trt*Rep** | 1.2283 | 0.4381 |
| **Rho(1)** | **Block*Trt*Rep** | 0.4201 | 0.2329 |
| **Rho(2)** | **Block*Trt*Rep** | 0.1146 | 0.2458 |

| Covariance Parameter Estimates | | | |
|---|---|---|---|
| **Cov Parm** | **Subject** | **Estimate** | **Standard Error** |
| **Rho(3)** | **Block*Trt*Rep** | 0.2262 | 0.2283 |
| **Rho(4)** | **Block*Trt*Rep** | 0.08827 | 0.2310 |

| Type III Tests of Fixed Effects | | | | |
|---|---|---|---|---|
| **Effect** | **Num DF** | **Den DF** | **F Value** | **Pr > F** |
| **Trt** | 4 | 14 | 2.56 | 0.0849 |
| **Date** | 4 | 82 | 15.75 | <.0001 |
| **Trt*Date** | 16 | 82 | 1.06 | 0.4020 |

| Trt*Date Least Squares Means | | | | | | |
|---|---|---|---|---|---|---|
| **Trt** | **Date** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** |
| **1** | **06JUL16** | -7.3750 | 0.4699 | 82 | -15.70 | <.0001 |
| **1** | **12JUL16** | -6.9250 | 0.2662 | 82 | -26.01 | <.0001 |
| **1** | **22JUL16** | -8.4200 | 0.3274 | 82 | -25.72 | <.0001 |
| **1** | **01AUG16** | -7.9500 | 0.4818 | 82 | -16.50 | <.0001 |
| **1** | **10AUG16** | -6.5700 | 0.5024 | 82 | -13.08 | <.0001 |
| **2** | **06JUL16** | -6.4932 | 0.4715 | 82 | -13.77 | <.0001 |
| **2** | **12JUL16** | -5.7982 | 0.2690 | 82 | -21.55 | <.0001 |
| **2** | **22JUL16** | -7.0982 | 0.3297 | 82 | -21.53 | <.0001 |
| **2** | **01AUG16** | -6.6182 | 0.4833 | 82 | -13.69 | <.0001 |
| **2** | **10AUG16** | -7.5982 | 0.5039 | 82 | -15.08 | <.0001 |
| **3** | **06JUL16** | -7.0618 | 0.4715 | 82 | -14.98 | <.0001 |
| **3** | **12JUL16** | -6.8618 | 0.2690 | 82 | -25.51 | <.0001 |
| **3** | **22JUL16** | -8.1518 | 0.3297 | 82 | -24.73 | <.0001 |
| **3** | **01AUG16** | -7.8118 | 0.4833 | 82 | -16.16 | <.0001 |
| **3** | **10AUG16** | -8.3118 | 0.5039 | 82 | -16.49 | <.0001 |

| Trt*Date Least Squares Means | | | | | | |
|---|---|---|---|---|---|---|
| **Trt** | **Date** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** |
| **4** | **06JUL16** | -6.6250 | 0.4699 | 82 | -14.10 | <.0001 |
| **4** | **12JUL16** | -6.2400 | 0.2662 | 82 | -23.44 | <.0001 |
| **4** | **22JUL16** | -7.4700 | 0.3274 | 82 | -22.82 | <.0001 |
| **4** | **01AUG16** | -7.6800 | 0.4818 | 82 | -15.94 | <.0001 |
| **4** | **10AUG16** | -7.8700 | 0.5024 | 82 | -15.66 | <.0001 |
| **6** | **06JUL16** | -6.4900 | 0.4699 | 82 | -13.81 | <.0001 |
| **6** | **12JUL16** | -6.7400 | 0.2662 | 82 | -25.31 | <.0001 |
| **6** | **22JUL16** | -7.8100 | 0.3274 | 82 | -23.85 | <.0001 |
| **6** | **01AUG16** | -7.0700 | 0.4818 | 82 | -14.68 | <.0001 |
| **6** | **10AUG16** | -7.7600 | 0.5024 | 82 | -15.44 | <.0001 |

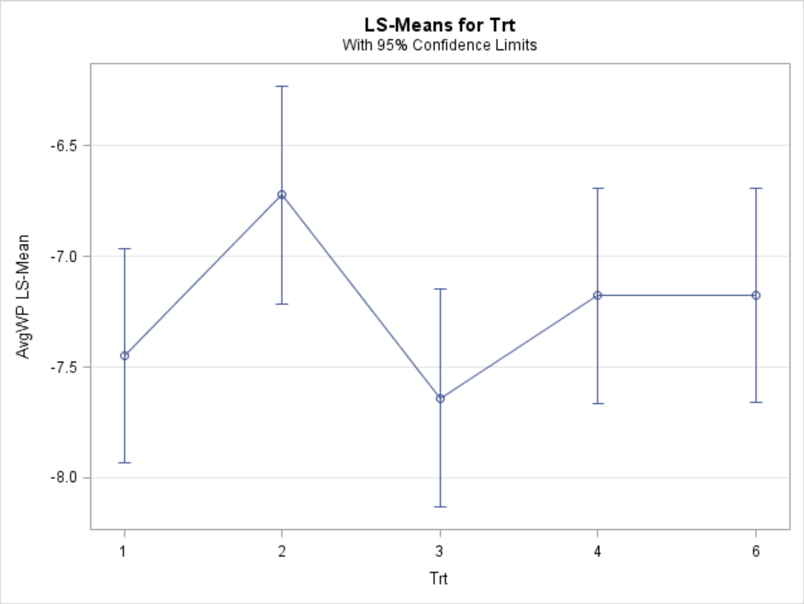
| Simple Effect Comparisons of Trt*Date Least Squares Means By Date | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Simple Effect Level** | **Trt** | **Trt** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** |
| **Date 06JUL2016** | **1** | **2** | -0.8818 | 0.6554 | 82 | -1.35 | 0.1821 |
| **Date 06JUL2016** | **1** | **3** | -0.3132 | 0.6554 | 82 | -0.48 | 0.6340 |
| **Date 06JUL2016** | **1** | **4** | -0.7500 | 0.6542 | 82 | -1.15 | 0.2550 |
| **Date 06JUL2016** | **1** | **6** | -0.8850 | 0.6542 | 82 | -1.35 | 0.1799 |
| **Date 06JUL2016** | **2** | **3** | 0.5687 | 0.6588 | 82 | 0.86 | 0.3905 |
| **Date 06JUL2016** | **2** | **4** | 0.1318 | 0.6554 | 82 | 0.20 | 0.8411 |
| **Date 06JUL2016** | **2** | **6** | -0.00316 | 0.6554 | 82 | -0.00 | 0.9962 |
| **Date 06JUL2016** | **3** | **4** | -0.4368 | 0.6554 | 82 | -0.67 | 0.5069 |
| **Date 06JUL2016** | **3** | **6** | -0.5718 | 0.6554 | 82 | -0.87 | 0.3855 |
| **Date 06JUL2016** | **4** | **6** | -0.1350 | 0.6542 | 82 | -0.21 | 0.8370 |
| **Date 12JUL2016** | **1** | **2** | -1.1268 | 0.3601 | 82 | -3.13 | 0.0024 |
| **Date 12JUL2016** | **1** | **3** | -0.06316 | 0.3601 | 82 | -0.18 | 0.8612 |
| **Date 12JUL2016** | **1** | **4** | -0.6850 | 0.3581 | 82 | -1.91 | 0.0592 |

**Simple Effect Comparisons of Trt*Date Least Squares Means By Date**

| Simple Effect Level | Trt | Trt | Estimate | Standard Error | DF | t Value | Pr > \|t\| |
|---|---|---|---|---|---|---|---|
| **Date 12JUL2016** | **1** | **6** | -0.1850 | 0.3581 | 82 | -0.52 | 0.6068 |
| **Date 12JUL2016** | **2** | **3** | 1.0637 | 0.3663 | 82 | 2.90 | 0.0047 |
| **Date 12JUL2016** | **2** | **4** | 0.4418 | 0.3601 | 82 | 1.23 | 0.2234 |
| **Date 12JUL2016** | **2** | **6** | 0.9418 | 0.3601 | 82 | 2.62 | 0.0106 |
| **Date 12JUL2016** | **3** | **4** | -0.6218 | 0.3601 | 82 | -1.73 | 0.0880 |
| **Date 12JUL2016** | **3** | **6** | -0.1218 | 0.3601 | 82 | -0.34 | 0.7360 |
| **Date 12JUL2016** | **4** | **6** | 0.5000 | 0.3581 | 82 | 1.40 | 0.1664 |
| **Date 22JUL2016** | **1** | **2** | -1.3218 | 0.4498 | 82 | -2.94 | 0.0043 |
| **Date 22JUL2016** | **1** | **3** | -0.2682 | 0.4498 | 82 | -0.60 | 0.5527 |
| **Date 22JUL2016** | **1** | **4** | -0.9500 | 0.4481 | 82 | -2.12 | 0.0370 |
| **Date 22JUL2016** | **1** | **6** | -0.6100 | 0.4481 | 82 | -1.36 | 0.1772 |
| **Date 22JUL2016** | **2** | **3** | 1.0537 | 0.4547 | 82 | 2.32 | 0.0230 |
| **Date 22JUL2016** | **2** | **4** | 0.3718 | 0.4498 | 82 | 0.83 | 0.4108 |
| **Date 22JUL2016** | **2** | **6** | 0.7118 | 0.4498 | 82 | 1.58 | 0.1173 |
| **Date 22JUL2016** | **3** | **4** | -0.6818 | 0.4498 | 82 | -1.52 | 0.1334 |
| **Date 22JUL2016** | **3** | **6** | -0.3418 | 0.4498 | 82 | -0.76 | 0.4494 |
| **Date 22JUL2016** | **4** | **6** | 0.3400 | 0.4481 | 82 | 0.76 | 0.4502 |
| **Date 01AUG2016** | **1** | **2** | -1.3318 | 0.6724 | 82 | -1.98 | 0.0510 |
| **Date 01AUG2016** | **1** | **3** | -0.1382 | 0.6724 | 82 | -0.21 | 0.8377 |
| **Date 01AUG2016** | **1** | **4** | -0.2700 | 0.6713 | 82 | -0.40 | 0.6886 |
| **Date 01AUG2016** | **1** | **6** | -0.8800 | 0.6713 | 82 | -1.31 | 0.1935 |
| **Date 01AUG2016** | **2** | **3** | 1.1937 | 0.6757 | 82 | 1.77 | 0.0810 |
| **Date 01AUG2016** | **2** | **4** | 1.0618 | 0.6724 | 82 | 1.58 | 0.1181 |
| **Date 01AUG2016** | **2** | **6** | 0.4518 | 0.6724 | 82 | 0.67 | 0.5035 |
| **Date 01AUG2016** | **3** | **4** | -0.1318 | 0.6724 | 82 | -0.20 | 0.8450 |
| **Date 01AUG2016** | **3** | **6** | -0.7418 | 0.6724 | 82 | -1.10 | 0.2731 |
| **Date 01AUG2016** | **4** | **6** | -0.6100 | 0.6713 | 82 | -0.91 | 0.3662 |

| Simple Effect Comparisons of Trt*Date Least Squares Means By Date | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Simple Effect Level** | **Trt** | **Trt** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** |
| **Date 10AUG2016** | **1** | **2** | 1.0282 | 0.7020 | 82 | 1.46 | 0.1469 |
| **Date 10AUG2016** | **1** | **3** | 1.7418 | 0.7020 | 82 | 2.48 | 0.0151 |
| **Date 10AUG2016** | **1** | **4** | 1.3000 | 0.7009 | 82 | 1.85 | 0.0672 |
| **Date 10AUG2016** | **1** | **6** | 1.1900 | 0.7009 | 82 | 1.70 | 0.0934 |
| **Date 10AUG2016** | **2** | **3** | 0.7137 | 0.7052 | 82 | 1.01 | 0.3145 |
| **Date 10AUG2016** | **2** | **4** | 0.2718 | 0.7020 | 82 | 0.39 | 0.6996 |
| **Date 10AUG2016** | **2** | **6** | 0.1618 | 0.7020 | 82 | 0.23 | 0.8182 |
| **Date 10AUG2016** | **3** | **4** | -0.4418 | 0.7020 | 82 | -0.63 | 0.5308 |
| **Date 10AUG2016** | **3** | **6** | -0.5518 | 0.7020 | 82 | -0.79 | 0.4341 |
| **Date 10AUG2016** | **4** | **6** | -0.1100 | 0.7009 | 82 | -0.16 | 0.8757 |

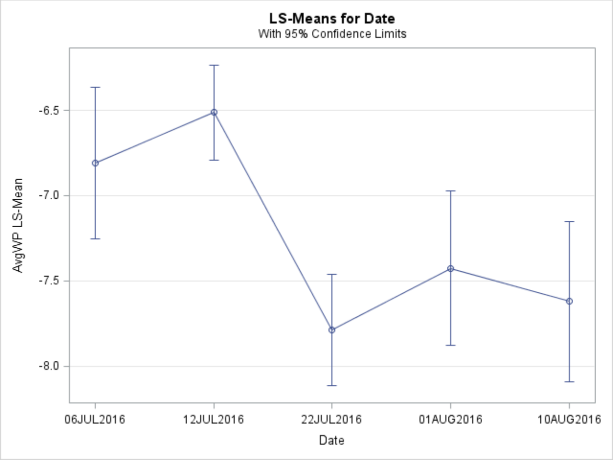
| Trt Least Squares Means | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Trt** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **1** | -7.4480 | 0.2261 | 14 | -32.94 | <.0001 | 0.05 | -7.9329 | -6.9631 |
| **2** | -6.7212 | 0.2294 | 14 | -29.30 | <.0001 | 0.05 | -7.2131 | -6.2292 |
| **3** | -7.6398 | 0.2294 | 14 | -33.31 | <.0001 | 0.05 | -8.1318 | -7.1479 |
| **4** | -7.1770 | 0.2261 | 14 | -31.74 | <.0001 | 0.05 | -7.6619 | -6.6921 |
| **6** | -7.1740 | 0.2261 | 14 | -31.73 | <.0001 | 0.05 | -7.6589 | -6.6891 |



| Differences of Trt Least Squares Means | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Trt** | **Trt** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **1** | **2** | -0.7268 | 0.3003 | 14 | -2.42 | 0.0297 | 0.05 | -1.3708 | -0.08285 |
| **1** | **3** | 0.1918 | 0.3003 | 14 | 0.64 | 0.5332 | 0.05 | -0.4521 | 0.8358 |
| **1** | **4** | -0.2710 | 0.2978 | 14 | -0.91 | 0.3782 | 0.05 | -0.9096 | 0.3676 |
| **1** | **6** | -0.2740 | 0.2978 | 14 | -0.92 | 0.3731 | 0.05 | -0.9126 | 0.3646 |
| **2** | **3** | 0.9187 | 0.3076 | 14 | 2.99 | 0.0098 | 0.05 | 0.2589 | 1.5785 |
| **2** | **4** | 0.4558 | 0.3003 | 14 | 1.52 | 0.1512 | 0.05 | -0.1881 | 1.0998 |
| **2** | **6** | 0.4528 | 0.3003 | 14 | 1.51 | 0.1537 | 0.05 | -0.1911 | 1.0968 |
| **3** | **4** | -0.4628 | 0.3003 | 14 | -1.54 | 0.1455 | 0.05 | -1.1068 | 0.1811 |
| **3** | **6** | -0.4658 | 0.3003 | 14 | -1.55 | 0.1431 | 0.05 | -1.1098 | 0.1781 |
| **4** | **6** | -0.00300 | 0.2978 | 14 | -0.01 | 0.9921 | 0.05 | -0.6416 | 0.6356 |

| Date Least Squares Means | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Date** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **06JUL16** | -6.8090 | 0.2227 | 82 | -30.58 | <.0001 | 0.05 | -7.2520 | -6.3660 |
| **12JUL16** | -6.5130 | 0.1400 | 82 | -46.51 | <.0001 | 0.05 | -6.7916 | -6.2344 |
| **22JUL16** | -7.7900 | 0.1639 | 82 | -47.53 | <.0001 | 0.05 | -8.1161 | -7.4639 |

| Date Least Squares Means | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Date** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **01AUG16** | -7.4260 | 0.2277 | 82 | -32.61 | <.0001 | 0.05 | -7.8790 | -6.9730 |
| **10AUG16** | -7.6220 | 0.2365 | 82 | -32.23 | <.0001 | 0.05 | -8.0924 | -7.1516 |



| Differences of Date Least Squares Means | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Date** | **Date** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **06JUL16** | **12JUL16** | -0.2960 | 0.1896 | 82 | -1.56 | 0.1223 | 0.05 | -0.6731 | 0.08114 |
| **06JUL16** | **22JUL16** | 0.9810 | 0.2451 | 82 | 4.00 | 0.0001 | 0.05 | 0.4935 | 1.4685 |
| **06JUL16** | **01AUG16** | 0.6170 | 0.2948 | 82 | 2.09 | 0.0394 | 0.05 | 0.03055 | 1.2034 |
| **06JUL16** | **10AUG16** | 0.8130 | 0.3031 | 82 | 2.68 | 0.0088 | 0.05 | 0.2101 | 1.4159 |
| **12JUL16** | **22JUL16** | 1.2770 | 0.1709 | 82 | 7.47 | <.0001 | 0.05 | 0.9369 | 1.6171 |
| **12JUL16** | **01AUG16** | 0.9130 | 0.2380 | 82 | 3.84 | 0.0002 | 0.05 | 0.4396 | 1.3864 |
| **12JUL16** | **10AUG16** | 1.1090 | 0.2487 | 82 | 4.46 | <.0001 | 0.05 | 0.6143 | 1.6037 |
| **22JUL16** | **01AUG16** | -0.3640 | 0.2270 | 82 | -1.60 | 0.1127 | 0.05 | -0.8156 | 0.08759 |
| **22JUL16** | **10AUG16** | -0.1680 | 0.2607 | 82 | -0.64 | 0.5211 | 0.05 | -0.6866 | 0.3506 |
| **01AUG16** | **10AUG16** | 0.1960 | 0.2931 | 82 | 0.67 | 0.5055 | 0.05 | -0.3870 | 0.7790 |

**APPENDIX J.** 2017 Midday Leaf Water Potential Statistical Analyses

| Model Information | |
|---|---|
| **Data Set** | WORK.LWP2 |
| **Response Variable** | AvgWP |
| **Response Distribution** | Gaussian |
| **Link Function** | Identity |

| Class Level Information | | |
|---|---|---|
| **Class** | **Levels** | **Values** |
| **Block** | 5 | 1 2 3 4 5 |
| **Trt** | 5 | 1 2 3 4 6 |
| **Date** | 5 | 07JUL2017 14JUL2017 20JUL2017 27JUL2017 10AUG2017 |
| **Rep** | 5 | E B A C D |

| | |
|---|---|
| **Number of Observations Read** | 125 |
| **Number of Observations Used** | 125 |

| Covariance Parameter Estimates | | | |
|---|---|---|---|
| **Cov Parm** | **Subject** | **Estimate** | **Standard Error** |
| **Block** | | 0 | . |
| **Block*Trt** | | 0.08194 | 0.04272 |
| **SP(POW)** | **Block*Trt*Rep** | 0.01934 | 233.18 |
| **Residual** | | 0.2295 | 0.03589 |

| Type III Tests of Fixed Effects | | | | |
|---|---|---|---|---|
| **Effect** | **Num DF** | **Den DF** | **F Value** | **Pr > F** |
| **Trt** | 4 | 14 | 20.26 | <.0001 |
| **Date** | 4 | 82 | 74.12 | <.0001 |

| Type III Tests of Fixed Effects | | | | |
|---|---|---|---|---|
| **Effect** | **Num DF** | **Den DF** | **F Value** | **Pr > F** |
| **Trt*Date** | 16 | 82 | 7.28 | <.0001 |

| Trt*Date Least Squares Means | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Trt** | **Date** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **1** | **07JUL17** | **-7.3200** | 0.2496 | 82 | -29.33 | <.0001 | 0.05 | -7.8165 | -6.8235 |
| **1** | **14JUL17** | **-6.2700** | 0.2496 | 82 | -25.12 | <.0001 | 0.05 | -6.7665 | -5.7735 |
| **1** | **20JUL17** | **-7.8100** | 0.2496 | 82 | -31.29 | <.0001 | 0.05 | -8.3065 | -7.3135 |
| **1** | **27JUL17** | **-9.3600** | 0.2496 | 82 | -37.50 | <.0001 | 0.05 | -9.8565 | -8.8635 |
| **1** | **10AUG17** | **-8.7600** | 0.2496 | 82 | -35.10 | <.0001 | 0.05 | -9.2565 | -8.2635 |
| **2** | **07JUL17** | **-5.3819** | 0.2589 | 82 | -20.79 | <.0001 | 0.05 | -5.8969 | -4.8668 |
| **2** | **14JUL17** | **-4.8219** | 0.2589 | 82 | -18.63 | <.0001 | 0.05 | -5.3369 | -4.3068 |
| **2** | **20JUL17** | **-5.7119** | 0.2589 | 82 | -22.06 | <.0001 | 0.05 | -6.2269 | -5.1968 |
| **2** | **27JUL17** | **-6.6719** | 0.2589 | 82 | -25.77 | <.0001 | 0.05 | -7.1869 | -6.1568 |
| **2** | **10AUG17** | **-7.4719** | 0.2589 | 82 | -28.86 | <.0001 | 0.05 | -7.9869 | -6.9568 |
| **3** | **07JUL17** | **-6.3180** | 0.2589 | 82 | -24.40 | <.0001 | 0.05 | -6.8330 | -5.8030 |
| **3** | **14JUL17** | **-6.1380** | 0.2589 | 82 | -23.71 | <.0001 | 0.05 | -6.6530 | -5.6230 |
| **3** | **20JUL17** | **-6.3180** | 0.2589 | 82 | -24.40 | <.0001 | 0.05 | -6.8330 | -5.8030 |
| **3** | **27JUL17** | **-7.5680** | 0.2589 | 82 | -29.23 | <.0001 | 0.05 | -8.0830 | -7.0530 |
| **3** | **10AUG17** | **-7.7680** | 0.2589 | 82 | -30.01 | <.0001 | 0.05 | -8.2830 | -7.2530 |
| **4** | **07JUL17** | **-6.3100** | 0.2496 | 82 | -25.28 | <.0001 | 0.05 | -6.8065 | -5.8135 |
| **4** | **14JUL17** | **-5.7000** | 0.2496 | 82 | -22.84 | <.0001 | 0.05 | -6.1965 | -5.2035 |
| **4** | **20JUL17** | **-6.3100** | 0.2496 | 82 | -25.28 | <.0001 | 0.05 | -6.8065 | -5.8135 |
| **4** | **27JUL17** | **-7.6500** | 0.2496 | 82 | -30.65 | <.0001 | 0.05 | -8.1465 | -7.1535 |
| **4** | **10AUG17** | **-8.0500** | 0.2496 | 82 | -32.25 | <.0001 | 0.05 | -8.5465 | -7.5535 |
| **6** | **07JUL17** | **-7.3400** | 0.2496 | 82 | -29.41 | <.0001 | 0.05 | -7.8365 | -6.8435 |
| **6** | **14JUL17** | **-5.6500** | 0.2496 | 82 | -22.64 | <.0001 | 0.05 | -6.1465 | -5.1535 |

| Trt*Date Least Squares Means | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Trt** | **Date** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **6** | **20JUL17** | **-5.4900** | 0.2496 | 82 | -22.00 | <.0001 | 0.05 | -5.9865 | -4.9935 |
| **6** | **27JUL17** | **-6.5200** | 0.2496 | 82 | -26.12 | <.0001 | 0.05 | -7.0165 | -6.0235 |
| **6** | **10AUG17** | **-6.1200** | 0.2496 | 82 | -24.52 | <.0001 | 0.05 | -6.6165 | -5.6235 |

| Simple Effect Comparisons of Trt*Date Least Squares Means By Date | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Simple Effect Level** | **Trt** | **Trt** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **Date 07JUL2017** | **1** | **2** | -1.9381 | 0.3596 | 82 | -5.39 | <.0001 | 0.05 | -2.6535 | -1.2228 |
| **Date 07JUL2017** | **1** | **3** | -1.0020 | 0.3596 | 82 | -2.79 | 0.0066 | 0.05 | -1.7174 | -0.2867 |
| **Date 07JUL2017** | **1** | **4** | -1.0100 | 0.3530 | 82 | -2.86 | 0.0053 | 0.05 | -1.7121 | -0.3079 |
| **Date 07JUL2017** | **1** | **6** | 0.02000 | 0.3530 | 82 | 0.06 | 0.9549 | 0.05 | -0.6821 | 0.7221 |
| **Date 07JUL2017** | **2** | **3** | 0.9361 | 0.3661 | 82 | 2.56 | 0.0124 | 0.05 | 0.2078 | 1.6644 |
| **Date 07JUL2017** | **2** | **4** | 0.9281 | 0.3596 | 82 | 2.58 | 0.0116 | 0.05 | 0.2128 | 1.6435 |
| **Date 07JUL2017** | **2** | **6** | 1.9581 | 0.3596 | 82 | 5.45 | <.0001 | 0.05 | 1.2428 | 2.6735 |
| **Date 07JUL2017** | **3** | **4** | -0.00796 | 0.3596 | 82 | -0.02 | 0.9824 | 0.05 | -0.7233 | 0.7074 |
| **Date 07JUL2017** | **3** | **6** | 1.0220 | 0.3596 | 82 | 2.84 | 0.0057 | 0.05 | 0.3067 | 1.7374 |
| **Date 07JUL2017** | **4** | **6** | 1.0300 | 0.3530 | 82 | 2.92 | 0.0045 | 0.05 | 0.3279 | 1.7321 |
| **Date 14JUL2017** | **1** | **2** | -1.4481 | 0.3596 | 82 | -4.03 | 0.0001 | 0.05 | -2.1635 | -0.7328 |
| **Date 14JUL2017** | **1** | **3** | -0.1320 | 0.3596 | 82 | -0.37 | 0.7144 | 0.05 | -0.8474 | 0.5833 |

| Simple Effect Comparisons of Trt*Date Least Squares Means By Date | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Simple Effect Level** | **Trt** | **Trt** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **Date 14JUL2017** | **1** | **4** | -0.5700 | 0.3530 | 82 | -1.61 | 0.1102 | 0.05 | -1.2721 | 0.1321 |
| **Date 14JUL2017** | **1** | **6** | -0.6200 | 0.3530 | 82 | -1.76 | 0.0827 | 0.05 | -1.3221 | 0.08213 |
| **Date 14JUL2017** | **2** | **3** | 1.3161 | 0.3661 | 82 | 3.59 | 0.0006 | 0.05 | 0.5878 | 2.0444 |
| **Date 14JUL2017** | **2** | **4** | 0.8781 | 0.3596 | 82 | 2.44 | 0.0168 | 0.05 | 0.1628 | 1.5935 |
| **Date 14JUL2017** | **2** | **6** | 0.8281 | 0.3596 | 82 | 2.30 | 0.0238 | 0.05 | 0.1128 | 1.5435 |
| **Date 14JUL2017** | **3** | **4** | -0.4380 | 0.3596 | 82 | -1.22 | 0.2267 | 0.05 | -1.1533 | 0.2774 |
| **Date 14JUL2017** | **3** | **6** | -0.4880 | 0.3596 | 82 | -1.36 | 0.1785 | 0.05 | -1.2033 | 0.2274 |
| **Date 14JUL2017** | **4** | **6** | -0.05000 | 0.3530 | 82 | -0.14 | 0.8877 | 0.05 | -0.7521 | 0.6521 |
| **Date 20JUL2017** | **1** | **2** | -2.0981 | 0.3596 | 82 | -5.83 | <.0001 | 0.05 | -2.8135 | -1.3828 |
| **Date 20JUL2017** | **1** | **3** | -1.4920 | 0.3596 | 82 | -4.15 | <.0001 | 0.05 | -2.2074 | -0.7767 |
| **Date 20JUL2017** | **1** | **4** | -1.5000 | 0.3530 | 82 | -4.25 | <.0001 | 0.05 | -2.2021 | -0.7979 |
| **Date 20JUL2017** | **1** | **6** | -2.3200 | 0.3530 | 82 | -6.57 | <.0001 | 0.05 | -3.0221 | -1.6179 |
| **Date 20JUL2017** | **2** | **3** | 0.6061 | 0.3661 | 82 | 1.66 | 0.1016 | 0.05 | -0.1222 | 1.3344 |
| **Date 20JUL2017** | **2** | **4** | 0.5981 | 0.3596 | 82 | 1.66 | 0.1001 | 0.05 | -0.1172 | 1.3135 |
| **Date 20JUL2017** | **2** | **6** | -0.2219 | 0.3596 | 82 | -0.62 | 0.5390 | 0.05 | -0.9372 | 0.4935 |
| **Date 20JUL2017** | **3** | **4** | -0.00796 | 0.3596 | 82 | -0.02 | 0.9824 | 0.05 | -0.7233 | 0.7074 |

| Simple Effect Comparisons of Trt*Date Least Squares Means By Date | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Simple Effect Level** | **Trt** | **Trt** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **Date 20JUL2017** | **3** | **6** | -0.8280 | 0.3596 | 82 | -2.30 | 0.0238 | 0.05 | -1.5433 | -0.1126 |
| **Date 20JUL2017** | **4** | **6** | -0.8200 | 0.3530 | 82 | -2.32 | 0.0226 | 0.05 | -1.5221 | -0.1179 |
| **Date 27JUL2017** | **1** | **2** | -2.6881 | 0.3596 | 82 | -7.48 | <.0001 | 0.05 | -3.4035 | -1.9728 |
| **Date 27JUL2017** | **1** | **3** | -1.7920 | 0.3596 | 82 | -4.98 | <.0001 | 0.05 | -2.5074 | -1.0767 |
| **Date 27JUL2017** | **1** | **4** | -1.7100 | 0.3530 | 82 | -4.84 | <.0001 | 0.05 | -2.4121 | -1.0079 |
| **Date 27JUL2017** | **1** | **6** | -2.8400 | 0.3530 | 82 | -8.05 | <.0001 | 0.05 | -3.5421 | -2.1379 |
| **Date 27JUL2017** | **2** | **3** | 0.8961 | 0.3661 | 82 | 2.45 | 0.0165 | 0.05 | 0.1678 | 1.6244 |
| **Date 27JUL2017** | **2** | **4** | 0.9781 | 0.3596 | 82 | 2.72 | 0.0080 | 0.05 | 0.2628 | 1.6935 |
| **Date 27JUL2017** | **2** | **6** | -0.1519 | 0.3596 | 82 | -0.42 | 0.6739 | 0.05 | -0.8672 | 0.5635 |
| **Date 27JUL2017** | **3** | **4** | 0.08204 | 0.3596 | 82 | 0.23 | 0.8201 | 0.05 | -0.6333 | 0.7974 |
| **Date 27JUL2017** | **3** | **6** | -1.0480 | 0.3596 | 82 | -2.91 | 0.0046 | 0.05 | -1.7633 | -0.3326 |
| **Date 27JUL2017** | **4** | **6** | -1.1300 | 0.3530 | 82 | -3.20 | 0.0019 | 0.05 | -1.8321 | -0.4279 |
| **Date 10AUG2017** | **1** | **2** | -1.2881 | 0.3596 | 82 | -3.58 | 0.0006 | 0.05 | -2.0035 | -0.5728 |
| **Date 10AUG2017** | **1** | **3** | -0.9920 | 0.3596 | 82 | -2.76 | 0.0072 | 0.05 | -1.7074 | -0.2767 |
| **Date 10AUG2017** | **1** | **4** | -0.7100 | 0.3530 | 82 | -2.01 | 0.0475 | 0.05 | -1.4121 | -0.00787 |
| **Date 10AUG2017** | **1** | **6** | -2.6400 | 0.3530 | 82 | -7.48 | <.0001 | 0.05 | -3.3421 | -1.9379 |

| Simple Effect Comparisons of Trt*Date Least Squares Means By Date | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Simple Effect Level** | **Trt** | **Trt** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **Date 10AUG2017** | **2** | **3** | 0.2961 | 0.3661 | 82 | 0.81 | 0.4210 | 0.05 | -0.4322 | 1.0244 |
| **Date 10AUG2017** | **2** | **4** | 0.5781 | 0.3596 | 82 | 1.61 | 0.1117 | 0.05 | -0.1372 | 1.2935 |
| **Date 10AUG2017** | **2** | **6** | -1.3519 | 0.3596 | 82 | -3.76 | 0.0003 | 0.05 | -2.0672 | -0.6365 |
| **Date 10AUG2017** | **3** | **4** | 0.2820 | 0.3596 | 82 | 0.78 | 0.4351 | 0.05 | -0.4333 | 0.9974 |
| **Date 10AUG2017** | **3** | **6** | -1.6480 | 0.3596 | 82 | -4.58 | <.0001 | 0.05 | -2.3633 | -0.9326 |
| **Date 10AUG2017** | **4** | **6** | -1.9300 | 0.3530 | 82 | -5.47 | <.0001 | 0.05 | -2.6321 | -1.2279 |

## **APPENDIX K.** Pruning Weight Data (2015 and 2016) and Statistical Analyses

| Year | Treatment | Plant # | Weight (lbs) | | Year | Treatment | Plant # | Weight (lbs) |
|---|---|---|---|---|---|---|---|---|
| 2015 | T1-A | 1 | 0.30 | | 2015 | T4-E | 1 | 0.46 |
| 2015 | T1-A | 2 | 0.08 | | 2015 | T4-E | 2 | 0.14 |
| 2015 | T1-B | 1 | 0.16 | | 2015 | T6-A | 1 | 0.54 |
| 2015 | T1-B | 2 | 0.08 | | 2015 | T6-A | 2 | 0.18 |
| 2015 | T1-C | 1 | 0.06 | | 2015 | T6-B | 1 | 0.40 |
| 2015 | T1-C | 2 | 0.10 | | 2015 | T6-B | 2 | . |
| 2015 | T1-D | 1 | 0.06 | | 2015 | T6-C | 1 | 0.16 |
| 2015 | T1-D | 2 | 0.04 | | 2015 | T6-C | 2 | 0.32 |
| 2015 | T1-E | 1 | 0.08 | | 2015 | T6-D | 1 | 0.40 |
| 2015 | T1-E | 2 | 0.04 | | 2015 | T6-D | 2 | 0.28 |
| 2015 | T2-A | 1 | 0.18 | | 2015 | T6-E | 1 | 0.22 |
| 2015 | T2-A | 2 | 0.16 | | 2015 | T6-E | 2 | 0.16 |
| 2015 | T2-B | 1 | 0.22 | | 2016 | T1-A | 3 | 0.12 |
| 2015 | T2-B | 2 | 0.12 | | 2016 | T1-A | 2 | 0.08 |
| 2015 | T2-C | 1 | 0.08 | | 2016 | T1-A | 1 | 0.02 |
| 2015 | T2-C | 2 | 0.16 | | 2016 | T1-A | 4 | 0.02 |
| 2015 | T2-D | 1 | 0.06 | | 2016 | T1-B | 3 | 0.08 |
| 2015 | T2-D | 2 | 0.06 | | 2016 | T1-B | 2 | 0.28 |
| 2015 | T2-E | 1 | 0.16 | | 2016 | T1-B | 1 | 0.20 |
| 2015 | T2-E | 2 | 0.06 | | 2016 | T1-B | 4 | 0.62 |
| 2015 | T3-A | 1 | 0.22 | | 2016 | T1-C | 3 | 0.12 |
| 2015 | T3-A | 2 | 0.20 | | 2016 | T1-C | 2 | 0.04 |
| 2015 | T3-B | 1 | 0.06 | | 2016 | T1-C | 1 | 0.10 |
| 2015 | T3-B | 2 | 0.06 | | 2016 | T1-C | 4 | 0.02 |
| 2015 | T3-C | 1 | 0.06 | | 2016 | T1-D | 3 | 0.00 |
| 2015 | T3-C | 2 | 0.04 | | 2016 | T1-D | 2 | 0.14 |
| 2015 | T3-D | 1 | 0.08 | | 2016 | T1-D | 1 | 0.00 |
| 2015 | T3-D | 2 | 0.02 | | 2016 | T1-D | 4 | 0.02 |
| 2015 | T3-E | 1 | 0.40 | | 2016 | T1-E | 3 | 0.02 |
| 2015 | T3-E | 2 | 0.08 | | 2016 | T1-E | 2 | 0.02 |
| 2015 | T4-A | 1 | 0.26 | | 2016 | T1-E | 1 | 0.00 |
| 2015 | T4-A | 2 | 0.20 | | 2016 | T1-E | 4 | 0.00 |
| 2015 | T4-B | 1 | 0.18 | | 2016 | T2-A | 3 | 0.00 |
| 2015 | T4-B | 2 | 0.16 | | 2016 | T2-A | 2 | 0.02 |
| 2015 | T4-C | 1 | 0.12 | | 2016 | T2-A | 1 | 0.00 |
| 2015 | T4-C | 2 | 0.10 | | 2016 | T2-A | 4 | 0.00 |
| 2015 | T4-D | 1 | 0.46 | | 2016 | T2-B | 3 | 0.02 |
| 2015 | T4-D | 2 | 0.38 | | 2016 | T2-B | 2 | 0.02 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2016 | T2-B | 1 | 0.02 | | 2016 | T4-C | 2 | 0.00 |
| 2016 | T2-B | 2 | 0.02 | | 2016 | T4-C | 1 | 0.04 |
| 2016 | T2-C | 3 | 0.00 | | 2016 | T4-C | 4 | 0.12 |
| 2016 | T2-C | 2 | 0.00 | | 2016 | T4-D | 3 | 0.18 |
| 2016 | T2-C | 1 | 0.00 | | 2016 | T4-D | 2 | 1.02 |
| 2016 | T2-C | 4 | 0.00 | | 2016 | T4-D | 1 | 1.22 |
| 2016 | T2-D | 3 | 0.02 | | 2016 | T4-D | 4 | 0.00 |
| 2016 | T2-D | 2 | 0.02 | | 2016 | T4-E | 3 | 0.46 |
| 2016 | T2-D | 1 | 0.00 | | 2016 | T4-E | 2 | 1.20 |
| 2016 | T2-D | 4 | 0.00 | | 2016 | T4-E | 1 | 0.52 |
| 2016 | T2-E | 3 | 0.02 | | 2016 | T4-E | 4 | 0.06 |
| 2016 | T2-E | 2 | 0.00 | | 2016 | T6-A | 3 | 0.90 |
| 2016 | T2-E | 1 | 0.00 | | 2016 | T6-A | 2 | 1.12 |
| 2016 | T2-E | 4 | 0.02 | | 2016 | T6-A | 1 | 0.60 |
| 2016 | T3-A | 3 | 0.34 | | 2016 | T6-A | 4 | 0.34 |
| 2016 | T3-A | 2 | 0.10 | | 2016 | T6-B | 3 | 1.46 |
| 2016 | T3-A | 1 | 0.50 | | 2016 | T6-B | 2 | 0.98 |
| 2016 | T3-A | 4 | 0.44 | | 2016 | T6-B | 1 | 0.00 |
| 2016 | T3-B | 3 | 0.10 | | 2016 | T6-B | 4 | 0.90 |
| 2016 | T3-B | 2 | 0.24 | | 2016 | T6-C | 3 | 0.40 |
| 2016 | T3-B | 1 | 0.30 | | 2016 | T6-C | 2 | 0.04 |
| 2016 | T3-B | 4 | 0.32 | | 2016 | T6-C | 1 | 0.36 |
| 2016 | T3-C | 3 | 0.00 | | 2016 | T6-C | 4 | 0.14 |
| 2016 | T3-C | 2 | 0.04 | | 2016 | T6-D | 3 | 0.60 |
| 2016 | T3-C | 1 | 0.02 | | 2016 | T6-D | 2 | 0.70 |
| 2016 | T3-C | 4 | 0.38 | | 2016 | T6-D | 1 | 0.48 |
| 2016 | T3-D | 3 | 0.00 | | 2016 | T6-D | 4 | 0.66 |
| 2016 | T3-D | 2 | 0.00 | | 2016 | T6-E | 3 | 0.00 |
| 2016 | T3-D | 1 | 0.00 | | 2016 | T6-E | 2 | 0.02 |
| 2016 | T3-D | 4 | 0.00 | | 2016 | T6-E | 1 | 0.32 |
| 2016 | T3-E | 3 | 0.16 | | 2016 | T6-E | 4 | 0.00 |
| 2016 | T3-E | 2 | 0.10 | | | | | |
| 2016 | T3-E | 1 | 0.10 | | | | | |
| 2016 | T3-E | 4 | 0.16 | | | | | |
| 2016 | T4-A | 3 | 0.78 | | | | | |
| 2016 | T4-A | 2 | 0.36 | | | | | |
| 2016 | T4-A | 1 | 0.22 | | | | | |
| 2016 | T4-A | 4 | 0.54 | | | | | |
| 2016 | T4-B | 3 | 0.42 | | | | | |
| 2016 | T4-B | 2 | 0.44 | | | | | |
| 2016 | T4-B | 1 | 0.06 | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2016 | T4-B | 4 | 0.50 | | | | | |
| 2016 | T4-C | 3 | 0.04 | | | | | |

| Model Information | |
|---|---|
| **Data Set** | WORK.PRUNE |
| **Response Variable** | AvgPrunWeight |
| **Response Distribution** | Gaussian |
| **Link Function** | Identity |

| Class Level Information | | |
|---|---|---|
| **Class** | **Levels** | **Values** |
| **Trt** | 5 | 1 2 3 4 6 |
| **Year** | 2 | 2015 2016 |
| **Block** | 5 | 1 2 3 4 5 |

| | |
|---|---|
| **Number of Observations Read** | 50 |
| **Number of Observations Used** | 50 |

| Covariance Parameter Estimates | | |
|---|---|---|
| **Cov Parm** | **Estimate** | **Standard Error** |
| **Block** | 0.001562 | 0.002699 |
| **Residual** | 0.02074 | 0.004891 |

| Type III Tests of Fixed Effects | | | | |
|---|---|---|---|---|
| **Effect** | **Num DF** | **Den DF** | **F Value** | **Pr > F** |
| **Year** | 1 | 36 | 1.88 | 0.1792 |
| **Trt** | 4 | 36 | 10.54 | <.0001 |
| **Trt*Year** | 4 | 36 | 1.95 | 0.1238 |

| Trt*Year Least Squares Means | | | | | | |
|---|---|---|---|---|---|---|
| **Trt** | **Year** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** |
| **1** | **2015** | 0.1000 | 0.06679 | 36 | 1.50 | 0.1430 |
| **1** | **2016** | 0.09500 | 0.06679 | 36 | 1.42 | 0.1635 |
| **2** | **2015** | 0.1338 | 0.06736 | 36 | 1.99 | 0.0547 |
| **2** | **2016** | 0.01676 | 0.06736 | 36 | 0.25 | 0.8049 |
| **3** | **2015** | 0.1142 | 0.06736 | 36 | 1.70 | 0.0985 |
| **3** | **2016** | 0.1572 | 0.06736 | 36 | 2.33 | 0.0253 |
| **4** | **2015** | 0.2460 | 0.06679 | 36 | 3.68 | 0.0008 |
| **4** | **2016** | 0.4090 | 0.06679 | 36 | 6.12 | <.0001 |
| **6** | **2015** | 0.3060 | 0.06679 | 36 | 4.58 | <.0001 |
| **6** | **2016** | 0.5010 | 0.06679 | 36 | 7.50 | <.0001 |

| Simple Effect Comparisons of Trt*Year Least Squares Means By Year | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Simple Effect Level** | **Trt** | **Trt** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** |
| **Year 2015** | **1** | **2** | -0.03376 | 0.09150 | 36 | -0.37 | 0.7143 |
| **Year 2015** | **1** | **3** | -0.01424 | 0.09150 | 36 | -0.16 | 0.8772 |
| **Year 2015** | **1** | **4** | -0.1460 | 0.09109 | 36 | -1.60 | 0.1177 |
| **Year 2015** | **1** | **6** | -0.2060 | 0.09109 | 36 | -2.26 | 0.0299 |
| **Year 2015** | **2** | **3** | 0.01952 | 0.09275 | 36 | 0.21 | 0.8345 |
| **Year 2015** | **2** | **4** | -0.1122 | 0.09150 | 36 | -1.23 | 0.2279 |
| **Year 2015** | **2** | **6** | -0.1722 | 0.09150 | 36 | -1.88 | 0.0679 |
| **Year 2015** | **3** | **4** | -0.1318 | 0.09150 | 36 | -1.44 | 0.1585 |
| **Year 2015** | **3** | **6** | -0.1918 | 0.09150 | 36 | -2.10 | 0.0432 |
| **Year 2015** | **4** | **6** | -0.06000 | 0.09109 | 36 | -0.66 | 0.5143 |
| **Year 2016** | **1** | **2** | 0.07824 | 0.09150 | 36 | 0.86 | 0.3982 |
| **Year 2016** | **1** | **3** | -0.06224 | 0.09150 | 36 | -0.68 | 0.5007 |
| **Year 2016** | **1** | **4** | -0.3140 | 0.09109 | 36 | -3.45 | 0.0015 |

| Simple Effect Comparisons of Trt*Year Least Squares Means By Year | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Simple Effect Level** | **Trt** | **Trt** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** |
| **Year 2016** | **1** | **6** | -0.4060 | 0.09109 | 36 | -4.46 | <.0001 |
| **Year 2016** | **2** | **3** | -0.1405 | 0.09275 | 36 | -1.51 | 0.1386 |
| **Year 2016** | **2** | **4** | -0.3922 | 0.09150 | 36 | -4.29 | 0.0001 |
| **Year 2016** | **2** | **6** | -0.4842 | 0.09150 | 36 | -5.29 | <.0001 |
| **Year 2016** | **3** | **4** | -0.2518 | 0.09150 | 36 | -2.75 | 0.0092 |
| **Year 2016** | **3** | **6** | -0.3438 | 0.09150 | 36 | -3.76 | 0.0006 |
| **Year 2016** | **4** | **6** | -0.09200 | 0.09109 | 36 | -1.01 | 0.3192 |

| Simple Effect Comparisons of Trt*Year Least Squares Means By Trt | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Simple Effect Level** | **Year** | **Year** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** |
| **Trt 1** | **2015** | **2016** | 0.005000 | 0.09109 | 36 | 0.05 | 0.9565 |
| **Trt 2** | **2015** | **2016** | 0.1170 | 0.09109 | 36 | 1.28 | 0.2072 |
| **Trt 3** | **2015** | **2016** | -0.04300 | 0.09109 | 36 | -0.47 | 0.6397 |
| **Trt 4** | **2015** | **2016** | -0.1630 | 0.09109 | 36 | -1.79 | 0.0819 |
| **Trt 6** | **2015** | **2016** | -0.1950 | 0.09109 | 36 | -2.14 | 0.0391 |

| Year Least Squares Means | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **2015** | 0.1800 | 0.03379 | 36 | 5.33 | <.0001 | 0.05 | 0.1115 | 0.2485 |
| **2016** | 0.2358 | 0.03379 | 36 | 6.98 | <.0001 | 0.05 | 0.1673 | 0.3043 |

| Differences of Year Least Squares Means | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Year** | **Estimate** | **Standard Error** | **DF** | **t Value** | **Pr > \|t\|** | **Alpha** | **Lower** | **Upper** |
| **2015** | **2016** | -0.05580 | 0.04073 | 36 | -1.37 | 0.1792 | 0.05 | -0.1384 | 0.02681 |

**Trt Least Squares Means**

| Trt | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper |
|---|---|---|---|---|---|---|---|---|
| **1** | 0.09750 | 0.04885 | 36 | 2.00 | 0.0536 | 0.05 | -0.00158 | 0.1966 |
| **2** | 0.07526 | 0.04963 | 36 | 1.52 | 0.1381 | 0.05 | -0.02539 | 0.1759 |
| **3** | 0.1357 | 0.04963 | 36 | 2.74 | 0.0096 | 0.05 | 0.03509 | 0.2364 |
| **4** | 0.3275 | 0.04885 | 36 | 6.70 | <.0001 | 0.05 | 0.2284 | 0.4266 |
| **6** | 0.4035 | 0.04885 | 36 | 8.26 | <.0001 | 0.05 | 0.3044 | 0.5026 |

**Differences of Trt Least Squares Means**

| Trt | Trt | Estimate | Standard Error | DF | t Value | Pr > \|t\| | Alpha | Lower | Upper |
|---|---|---|---|---|---|---|---|---|---|
| **1** | **2** | 0.02224 | 0.06500 | 36 | 0.34 | 0.7342 | 0.05 | -0.1096 | 0.1541 |
| **1** | **3** | -0.03824 | 0.06500 | 36 | -0.59 | 0.5600 | 0.05 | -0.1701 | 0.09358 |
| **1** | **4** | -0.2300 | 0.06441 | 36 | -3.57 | 0.0010 | 0.05 | -0.3606 | -0.09938 |
| **1** | **6** | -0.3060 | 0.06441 | 36 | -4.75 | <.0001 | 0.05 | -0.4366 | -0.1754 |
| **2** | **3** | -0.06048 | 0.06674 | 36 | -0.91 | 0.3708 | 0.05 | -0.1958 | 0.07488 |
| **2** | **4** | -0.2522 | 0.06500 | 36 | -3.88 | 0.0004 | 0.05 | -0.3841 | -0.1204 |
| **2** | **6** | -0.3282 | 0.06500 | 36 | -5.05 | <.0001 | 0.05 | -0.4601 | -0.1964 |
| **3** | **4** | -0.1918 | 0.06500 | 36 | -2.95 | 0.0056 | 0.05 | -0.3236 | -0.05994 |
| **3** | **6** | -0.2678 | 0.06500 | 36 | -4.12 | 0.0002 | 0.05 | -0.3996 | -0.1359 |
| **4** | **6** | -0.07600 | 0.06441 | 36 | -1.18 | 0.2457 | 0.05 | -0.2066 | 0.05462 |

## **APPENDIX L**. Harvest Data 2016 & 2017

| Year | Trt | Plant # | Cluster # | Total Cluster Weight (oz) | Total Cluster Weight (g) | Avg Cluster Weight (g) | Berry Sample Weight (g) | Avg Berry Weight | °Brix | pH | TA (g/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2016 | T1-A | 3 | 74 | 181 | 5131.26 | 69.34 | 168.86 | 1.6886 | 14 | 3.11 | 11.59 |
| 2016 | T1-A | 2 | 89 | 214.5 | 6080.97 | 68.33 | 179.59 | 1.7959 | 14.6 | 3.11 | 11.47 |
| 2016 | T1-A | 1 | 46 | 81 | 2296.31 | 49.92 | 192.2 | 1.922 | 15.7 | 3.17 | 11.94 |
| 2016 | T1-A | 4 | 37 | 75 | 2126.21 | 57.47 | 194.59 | 1.9459 | 16.3 | 3.15 | 8.08 |
| 2016 | T1-B | 3 | 32 | 62 | 1757.67 | 54.93 | 177.59 | 1.7759 | 15.2 | 3.03 | 11.4 |
| 2016 | T1-B | 2 | 111 | 192 | 5443.10 | 49.04 | 178.44 | 1.7844 | 15.6 | 3.07 | 9.055 |
| 2016 | T1-B | 1 | 56 | 82.5 | 2338.83 | 41.76 | 163.59 | 1.6359 | 16 | 3.25 | 11.39 |
| 2016 | T1-B | 4 | 53 | 163.5 | 4635.14 | 87.46 | 192.51 | 1.9251 | 14.2 | 3.11 | 12.22 |
| 2016 | T1-C | 3 | 77 | 146 | 4139.03 | 53.75 | 180.65 | 1.8065 | 15.9 | 3.2 | 9.79 |
| 2016 | T1-C | 2 | 30 | 65.5 | 1856.89 | 61.90 | 176.85 | 1.7685 | 15.3 | 3.118 | 10.72 |
| 2016 | T1-C | 1 | 46 | 91 | 2579.80 | 56.08 | 179.17 | 1.7917 | 16 | 3.16 | 10.52 |
| 2016 | T1-C | 4 |  |  |  |  |  |  |  |  |  |
| 2016 | T1-D | 3 | 27 | 48.5 | 1374.95 | 50.92 | 165.87 | 1.6587 | 17 | 3.24 | 7.935 |
| 2016 | T1-D | 2 | 39 | 85.5 | 2423.88 | 62.15 | 189.31 | 1.8931 | 16.6 | 3.25 | 8.997 |
| 2016 | T1-D | 1 | 26 | 37 | 1048.93 | 40.34 | 187.35 | 1.8735 | 17.8 | 3.22 | 8.543 |
| 2016 | T1-D | 4 | 35 | 54.5 | 1545.05 | 44.14 | 183.75 | 1.8375 | 16.4 | 3.21 | 9.297 |
| 2016 | T1-E | 3 | 51 | 129.5 | 3671.26 | 71.99 | 188.22 | 1.8822 | 14.6 | 3.17 | 10.21 |
| 2016 | T1-E | 2 | 22 | 49 | 1389.13 | 63.14 | 173.54 | 1.7354 | 16.2 | 3.21 | 10.44 |
| 2016 | T1-E | 1 | 7 | 14 | 396.89 | 56.70 | 190.89 | 1.9089 | 16.2 | 3.21 | 13.74 |
| 2016 | T1-E | 4 | 17 | 44 | 1247.38 | 73.38 | 198.64 | 1.9864 | 16.3 | 3.14 | 8.916 |
| 2016 | T2-A | 3 |  |  |  |  |  |  |  |  |  |
| 2016 | T2-A | 2 | 32 | 68.5 | 1941.94 | 60.69 | 202.47 | 2.0247 | 15.2 | 3.16 | 9.469 |
| 2016 | T2-A | 1 | 33 | 81 | 2296.31 | 69.59 | 181.08 | 1.8108 | 15.8 | 3.24 | 8.337 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2016 | T2-A | 4 | 43 | 98.5 | 2792.43 | 64.94 | 195.08 | 1.9508 | 16.8 | 3.17 | 7.961 |
| 2016 | T2-B | 3 | | | | | | | | | |
| 2016 | T2-B | 2 | | | | | | | | | |
| 2016 | T2-B | 1 | | | | | | | | | |
| 2016 | T2-B | 4 | | | | | | | | | |
| 2016 | T2-C | 3 | | | | | | | | | |
| 2016 | T2-C | 2 | | | | | | | | | |
| 2016 | T2-C | 1 | | | | | | | | | |
| 2016 | T2-C | 4 | 20 | 38.5 | 1091.46 | 54.57 | | | | | |
| 2016 | T2-D | 3 | 41 | 50 | 1417.47 | 34.57 | 171.56 | 1.7156 | 12.9 | 3.04 | 12.28 |
| 2016 | T2-D | 2 | 15 | 42.5 | 1204.85 | 80.32 | 237.09 | 2.3709 | 17.2 | 3.09 | 9.627 |
| 2016 | T2-D | 1 | 11 | 26.5 | 751.26 | 68.30 | 190.63 | 1.9063 | 17 | 3.07 | 8.901 |
| 2016 | T2-D | 4 | 29 | 74 | 2097.86 | 72.34 | 174.82 | 1.7482 | 15.3 | 2.93 | 10.8 |
| 2016 | T2-E | 3 | 64 | 131.5 | 3727.96 | 58.25 | 183.12 | 1.8312 | 15.5 | 3.2 | 9.54 |
| 2016 | T2-E | 2 | 21 | 30.5 | 864.66 | 41.17 | 177.5 | 1.775 | 16.6 | 3.14 | 10.03 |
| 2016 | T2-E | 1 | | | | | | | | | |
| 2016 | T2-E | 4 | 46 | 62 | 1757.67 | 38.21 | 167.64 | 1.6764 | 15.6 | 3.13 | 9.564 |
| 2016 | T3-A | 3 | 98 | 219.5 | 6222.71 | 63.50 | 213.09 | 2.1309 | 16.1 | 3.18 | 9.7 |
| 2016 | T3-A | 2 | 52 | 144.5 | 4096.50 | 78.78 | 197.57 | 1.9757 | 15.7 | 3.19 | 9.163 |
| 2016 | T3-A | 1 | 48 | 135.5 | 3841.36 | 80.03 | 201.12 | 2.0112 | 15.7 | 3.22 | 10.63 |
| 2016 | T3-A | 4 | 51 | 163 | 4620.97 | 90.61 | 210.79 | 2.1079 | 16.1 | 3.16 | 9.758 |
| 2016 | T3-B | 3 | 77 | 171 | 4847.76 | 62.96 | 184.15 | 1.8415 | 16.3 | 3.21 | 9.572 |
| 2016 | T3-B | 2 | 52 | 119 | 3373.59 | 64.88 | 201.39 | 2.0139 | 14.6 | 3.13 | 12.45 |
| 2016 | T3-B | 1 | 97 | 160.5 | 4550.09 | 46.91 | 170.66 | 1.7066 | 15.4 | 3.18 | 10.07 |
| 2016 | T3-B | 4 | 65 | 174.5 | 4946.99 | 76.11 | 188.21 | 1.8821 | 15.6 | 3.24 | 11.17 |
| 2016 | T3-C | 3 | 31 | 59.5 | 1686.79 | 54.41 | 180.27 | 1.8027 | 17.6 | 3.28 | 8.387 |
| 2016 | T3-C | 2 | 37 | 79.5 | 2253.78 | 60.91 | 170.24 | 1.7024 | 15.7 | 3.17 | 10.93 |
| 2016 | T3-C | 1 | 41 | 84.5 | 2395.53 | 58.43 | 191.6 | 1.916 | 17.3 | 3.3 | 9.19 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2016 | T3-C | 4 | 54 | 91 | 2579.80 | 47.77 | 171.75 | 1.7175 | 17 | 3.22 | 8.357 |
| 2016 | T3-D | 3 | 40 | 102.5 | 2905.82 | 72.65 | 180.66 | 1.8066 | 15.2 | 3.1 | 11.09 |
| 2016 | T3-D | 2 | 34 | 66 | 1871.07 | 55.03 | 183.02 | 1.8302 | 16.3 | 3.2 | 10.15 |
| 2016 | T3-D | 1 | | | | | | | | | |
| 2016 | T3-D | 4 | 7 | 10.5 | 297.67 | 42.52 | 189.42 | 1.8942 | 16 | 3.26 | 11.13 |
| 2016 | T3-E | 3 | 62 | 127 | 3600.39 | 58.07 | 165.72 | 1.6572 | 16.7 | 3.24 | 8.8 |
| 2016 | T3-E | 2 | 93 | 155.5 | 4408.35 | 47.40 | 173.28 | 1.7328 | 17.1 | 3.29 | 8.248 |
| 2016 | T3-E | 1 | 68 | 89.5 | 2537.28 | 37.31 | 159.7 | 1.597 | 16.1 | 3.22 | 9.06 |
| 2016 | T3-E | 4 | 65 | 113 | 3203.49 | 49.28 | 183.95 | 1.8395 | 16.7 | 3.3 | 8.558 |
| 2016 | T4-A | 3 | 122 | 81.5 | 2310.48 | 18.94 | 198.78 | 1.9878 | 16 | 3.09 | 9.54 |
| 2016 | T4-A | 2 | 75 | 163 | 4620.97 | 61.61 | 178.69 | 1.7869 | 13.3 | 3.21 | 11.55 |
| 2016 | T4-A | 1 | 103 | 200 | 5669.90 | 55.05 | 200.94 | 2.0094 | 12.7 | 3.04 | 13.14 |
| 2016 | T4-A | 4 | 55 | 151 | 4280.77 | 77.83 | 199.38 | 1.9938 | 15.6 | 3.23 | 8.395 |
| 2016 | T4-B | 3 | 63 | 123.5 | 3501.16 | 55.57 | 168.51 | 1.6851 | 13.1 | 2.99 | 13.62 |
| 2016 | T4-B | 2 | 57 | 128.5 | 3642.91 | 63.91 | 203.12 | 2.0312 | 14.6 | 2.95 | 11.53 |
| 2016 | T4-B | 1 | 38 | 98.5 | 2792.43 | 73.48 | 160.12 | 1.6012 | 14 | 3.03 | 11.22 |
| 2016 | T4-B | 4 | 58 | 119.5 | 3387.76 | 58.41 | 184.18 | 1.8418 | 14.4 | 2.75 | 9.773 |
| 2016 | T4-C | 3 | | | | | | | | | |
| 2016 | T4-C | 2 | 44 | 55 | 1559.22 | 35.44 | 178.44 | 1.7844 | 15.5 | 3.06 | 9.782 |
| 2016 | T4-C | 1 | 36 | 80 | 2267.96 | 63.00 | 175.95 | 1.7595 | 14.9 | 3.18 | 9.084 |
| 2016 | T4-C | 4 | 37 | 99 | 2806.60 | 75.85 | 207.17 | 2.0717 | 15.9 | 3.14 | 9.623 |
| 2016 | T4-D | 3 | 28 | 60 | 1700.97 | 60.75 | 228.55 | 2.2855 | 17.2 | 3.15 | 7.876 |
| 2016 | T4-D | 2 | 96 | 287.5 | 8150.48 | 84.90 | 203.24 | 2.0324 | 15.4 | 3.25 | 8.669 |
| 2016 | T4-D | 1 | 50 | 153.5 | 4351.65 | 87.03 | 201.12 | 2.0112 | 15.5 | 2.96 | 8.342 |
| 2016 | T4-D | 4 | | | | | | | | | |
| 2016 | T4-E | 3 | 98 | 188.5 | 5343.88 | 54.53 | 169.97 | 1.6997 | 14.1 | 3.07 | 11.96 |
| 2016 | T4-E | 2 | 56 | 167 | 4734.37 | 84.54 | 174.13 | 1.7413 | 15.7 | 2.89 | 9.626 |
| 2016 | T4-E | 1 | 45 | 115 | 3260.19 | 72.45 | 212.09 | 2.1209 | 16.4 | 3.28 | 7.907 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2016 | T4-E | 4 | 59 | 116 | 3288.54 | 55.74 | 184.13 | 1.8413 | 15.4 | 3.21 | 8.903 |
| 2016 | T6-A | 3 | 21 | 30.5 | 864.66 | 41.17 | 202.99 | 2.0299 | 16 | 3.31 | 9.907 |
| 2016 | T6-A | 2 | 19 | 46.5 | 1318.25 | 69.38 | 254.77 | 2.5477 | 15.6 | 2.91 | 12.28 |
| 2016 | T6-A | 1 | | | | | | | | | |
| 2016 | T6-A | 4 | | | | | | | | | |
| 2016 | T6-B | 3 | 103 | 238 | 6747.18 | 65.51 | 207.82 | 2.0782 | 15.5 | 3.19 | 9.376 |
| 2016 | T6-B | 2 | 88 | 217.5 | 6166.01 | 70.07 | 217.38 | 2.1738 | 16.4 | 3.34 | 7.66 |
| 2016 | T6-B | 1 | | | | | | | | | |
| 2016 | T6-B | 4 | 55 | 83.5 | 2367.18 | 43.04 | 163.64 | 1.6364 | 17.2 | 3.34 | 8.835 |
| 2016 | T6-C | 3 | 74 | 152 | 4309.12 | 58.23 | 205.81 | 2.0581 | 16.3 | 3.38 | 8.831 |
| 2016 | T6-C | 2 | 27 | 53.5 | 1516.70 | 56.17 | 182.1 | 1.821 | 15.8 | 3.22 | 9.355 |
| 2016 | T6-C | 1 | 50 | 107.5 | 3047.57 | 60.95 | 169.54 | 1.6954 | 16.3 | 2.99 | 8.948 |
| 2016 | T6-C | 4 | 46 | 78 | 2211.26 | 48.07 | 210.94 | 2.1094 | 15.3 | 3.17 | 11.17 |
| 2016 | T6-D | 3 | 86 | 214.5 | 6080.97 | 70.71 | 232.71 | 2.3271 | 16.4 | 3.28 | 9.22 |
| 2016 | T6-D | 2 | 99 | 205 | 5811.65 | 58.70 | 170.68 | 1.7068 | 16.9 | 3.21 | 8 |
| 2016 | T6-D | 1 | 105 | 222 | 6293.59 | 59.94 | 192.14 | 1.9214 | 16.5 | 3.13 | 9.587 |
| 2016 | T6-D | 4 | 78 | 158 | 4479.22 | 57.43 | 178.94 | 1.7894 | 16 | 3.3 | 8.173 |
| 2016 | T6-E | 3 | 11 | 17 | 481.94 | 43.81 | 170.11 | 1.7011 | 18 | 3.24 | 8.203 |
| 2016 | T6-E | 2 | 27 | 52 | 1474.17 | 54.60 | 195.73 | 1.9573 | 16.4 | 3.14 | 12 |
| 2016 | T6-E | 1 | 5 | 5 | 141.75 | 28.35 | 161.1 | 1.611 | 17.7 | 3.31 | 9.333 |
| 2016 | T6-E | 4 | 7 | 7.5 | 212.62 | 30.37 | 153.84 | 1.5384 | 16.7 | 3.15 | 12.54 |
| 2017 | T1-A | 1 | 183 | 18.4 | 8346.10 | 45.61 | 94.1 | 1.88 | 18.4 | 3.19 | 9.6 |
| 2017 | T1-A | 2 | 104 | 9.6 | 4354.49 | 41.87 | 98.98 | 1.98 | 18.6 | 3.35 | 7.81 |
| 2017 | T1-B | 1 | 147 | 20.8 | 9434.72 | 64.18 | 122.74 | 2.45 | 17.5 | 3.44 | 5.98 |
| 2017 | T1-B | 2 | 91 | 7.6 | 3447.30 | 37.88 | 168.31 | 3.37 | 17.5 | 3.5 | 8.08 |
| 2017 | T1-C | 1 | 120 | 9.9 | 4490.56 | 37.42 | 116.38 | 2.33 | 17.9 | 3.42 | 7.56 |
| 2017 | T1-C | 2 | 128 | 11.5 | 5216.31 | 40.75 | 97.66 | 1.95 | 16.9 | 3.5 | 6.04 |
| 2017 | T1-D | 1 | 120 | 10.5 | 4762.72 | 39.69 | 124.4 | 2.49 | 18.3 | 3.35 | 7.75 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 | T1-D | 2 | 66 | 5.4 | 2449.40 | 37.11 | 99.81 | 2.00 | 19.9 | 3.56 | 6.32 |
| 2017 | T1-E | 1 | 71 | 7.2 | 3265.87 | 46.00 | 104.62 | 2.09 | 17.9 | 3.47 | 8.14 |
| 2017 | T1-E | 2 | 89 | 9.1 | 4127.69 | 46.38 | 97.77 | 1.96 | 17.5 | 3.39 | 8.3 |
| 2017 | T2-A | 1 | 75 | 6.4 | 2902.99 | 38.71 | 102.94 | 2.06 | 16 | 3.32 | 8.31 |
| 2017 | T2-A | 2 | 64 | 4.7 | 2131.88 | 33.31 | 110.71 | 2.21 | 18.4 | 3.38 | 7.51 |
| 2017 | T2-B | 1 | 50 | 3.2 | 1451.50 | 29.03 | 111.84 | 2.24 | 13.4 | 3.21 | 10.17 |
| 2017 | T2-B | 2 | 47 | 3.2 | 1451.50 | 30.88 | 115.81 | 2.32 | 15.6 | 3.26 | 9.44 |
| 2017 | T2-C | 1 | 22 | 0.8 | 362.87 | 16.49 | 98.91 | 1.98 | 15.6 | 3.3 | 8.73 |
| 2017 | T2-C | 2 | 50 | 4.5 | 2041.17 | 40.82 | 124.24 | 2.48 | 16.7 | 3.2 | 10.03 |
| 2017 | T2-D | 1 | 57 | 4.2 | 1905.09 | 33.42 | 92.36 | 1.85 | 19.6 | 3.36 | 8.34 |
| 2017 | T2-D | 2 | 48 | 2.4 | 1088.62 | 22.68 | 95.18 | 1.90 | 17.5 | 3.29 | 8.71 |
| 2017 | T2-E | 1 | 43 | 2.4 | 1088.62 | 25.32 | 89.03 | 1.78 | 18.8 | 3.34 | 7.34 |
| 2017 | T2-E | 2 | 68 | 3.1 | 1406.14 | 20.68 | 76.32 | 1.53 | 19.6 | 3.35 | 6.02 |
| 2017 | T3-A | 1 | 199 | 21.8 | 9888.31 | 49.69 | 104.62 | 2.09 | 15.6 | 3.46 | 7.71 |
| 2017 | T3-A | 2 | 135 | 19.2 | 8708.97 | 64.51 | 118.06 | 2.36 | 15.9 | 3.34 | 7.35 |
| 2017 | T3-B | 1 | 158 | 15.5 | 7030.68 | 44.50 | 98.41 | 1.97 | 18 | 3.44 | 6.42 |
| 2017 | T3-B | 2 | 121 | 13.4 | 6078.14 | 50.23 | 123.32 | 2.47 | 17.5 | 3.48 | 6.37 |
| 2017 | T3-C | 1 | 88 | 7.2 | 3265.87 | 37.11 | 90.28 | 1.81 | 18.7 | 3.43 | 5.46 |
| 2017 | T3-C | 2 | 224 | 16.3 | 7393.56 | 33.01 | 134.38 | 2.69 | 18.9 | 3.5 | 7.35 |
| 2017 | T3-D | 1 | 91 | 7.9 | 3583.38 | 39.38 | 104.18 | 2.08 | 18.7 | 3.32 | 5.48 |
| 2017 | T3-D | 2 | 55 | 2.9 | 1315.42 | 23.92 | 73.29 | 1.47 | 19.4 | 3.31 | 6.95 |
| 2017 | T3-E | 1 | 99 | 8.8 | 3991.61 | 40.32 | 101.66 | 2.03 | 19.7 | 3.63 | 5.67 |
| 2017 | T3-E | 2 | 10 | 3.9 | 1769.01 | 176.90 | 93.01 | 1.86 | 19.2 | 3.68 | 6.09 |
| 2017 | T4-A | 1 | 47 | 3.5 | 1587.57 | 33.78 | 90.34 | 1.81 | 13.8 | 3.3 | 8.55 |
| 2017 | T4-A | 2 | 38 | 2.5 | 1133.98 | 29.84 | 84.54 | 1.69 | 14.6 | 3.46 | 8.63 |
| 2017 | T4-B | 1 | 83 | 5.4 | 2449.40 | 29.51 | 82.39 | 1.65 | 15.9 | 3.36 | 8.25 |
| 2017 | T4-B | 2 | 73 | 4.5 | 2041.17 | 27.96 | 111.74 | 2.23 | 15.4 | 3.28 | 8.21 |
| 2017 | T4-C | 1 | 44 | 2.9 | 1315.42 | 29.90 | 75.63 | 1.51 | 14.6 | 3.32 | 7.63 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 | T4-C | 2 | 60 | 4 | 1814.37 | 30.24 | 93.45 | 1.87 | 16 | 3.33 | 7.45 |
| 2017 | T4-D | 1 | 286 | 25.8 | 11702.68 | 40.92 | 123.8 | 2.48 | 16.7 | 3.44 | 7.55 |
| 2017 | T4-D | 2 | 204 | 18.5 | 8391.46 | 41.13 | 125.16 | 2.50 | 15.9 | 3.39 | 7.55 |
| 2017 | T4-E | 1 | 107 | 12.8 | 5805.98 | 54.26 | 104.81 | 2.10 | 17.1 | 3.38 | 8.52 |
| 2017 | T4-E | 2 | 114 | 11.3 | 5125.59 | 44.96 | 97.81 | 1.96 | 16.5 | 3.25 | 9.47 |
| 2017 | T6-A | 1 | 152 | 19 | 8618.26 | 56.70 | 112.47 | 2.25 | 16.6 | 3.2 | 8.22 |
| 2017 | T6-A | 2 | 172 | 24.8 | 11249.09 | 65.40 | 113.67 | 2.27 | 16.6 | 3.39 | 8.7 |
| 2017 | T6-B | 1 | 209 | 17.3 | 7847.15 | 37.55 | 115.96 | 2.32 | 17.5 | 3.35 | 7.55 |
| 2017 | T6-B | 2 | 52 | 2.3 | 1043.26 | 20.06 | 95.39 | 1.91 | 16.6 | 3.37 | 8.1 |
| 2017 | T6-C | 1 | 167 | 36.2 | 16420.04 | 98.32 | 107.89 | 2.16 | 16.3 | 3.41 | 8.67 |
| 2017 | T6-C | 2 | 195 | 14.3 | 6486.37 | 33.26 | 112.23 | 2.24 | 16.1 | 3.41 | 8.41 |
| 2017 | T6-D | 1 | 161 | 18.2 | 8255.38 | 51.28 | 106.4 | 2.13 | 18 | 3.4 | 7.72 |
| 2017 | T6-D | 2 | 142 | 17.5 | 7937.87 | 55.90 | 105.26 | 2.11 | 17.3 | 3.36 | 8.4 |
| 2017 | T6-E | 1 | 158 | 15.5 | 7030.68 | 44.50 | 99.26 | 1.99 | 17.1 | 3.42 | 8.35 |
| 2017 | T6-E | 2 | 97 | 7.6 | 3447.30 | 35.54 | 88.35 | 1.77 | 18 | 3.57 | 7.89 |

**APPENDIX M.** Soil Samples 2015, 2016 & 2017

| Year | Trt | Block | pH | Buffer pH | OM % | Bulk Density | NO3 ppm | Bray 1 P ppm | K ppm | Ca ppm | Mg ppm | Na ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2015 | T1-E | blk 1 | 6.4 | 6.9 | 2.3 | 1.35 | 2 | 5.6 | 254 | 4058 | 977 | 42 |
| 2015 | T2-B | blk 1 | 6.1 | 6.7 | 2.5 | 1.3 | 2 | 6.6 | 284 | 3222 | 763 | 16 |
| 2015 | T3-A | blk 1 | 5.9 | 6.6 | 2.3 | 1.26 | 3 | 7.8 | 208 | 2918 | 622 | 18 |
| 2015 | T4-C | blk 1 | 6.4 | 6.7 | 2.4 | 1.31 | 2 | 5.6 | 227 | 3665 | 1001 | 131 |
| 2015 | T6-A | blk 1 | 6.1 | 6.7 | 2.3 | 1.31 | 5 | 11.1 | 272 | 3397 | 774 | 14 |
| 2015 | T1-B | blk 2 | 6.4 | 7 | 1.9 | 1.29 | 2 | 8 | 239 | 3615 | 751 | 23 |
| 2015 | T2-C | blk 2 | 6.2 | 6.7 | 2.3 | 1.32 | 1 | 4.9 | 237 | 3289 | 794 | 21 |
| 2015 | T3-B | blk 2 | 6 | 6.7 | 2.3 | 1.32 | 2 | 4.3 | 214 | 3691 | 667 | 22 |
| 2015 | T4-E | blk 2 | 6.2 | 6.8 | 1.9 | 1.24 | 2 | 12 | 207 | 3070 | 725 | 15 |
| 2015 | T6-B | blk 2 | 6.2 | 6.8 | 2 | 1.34 | 2 | 8.7 | 247 | 3459 | 852 | 13 |
| 2015 | T1-A | blk 3 | 6.4 | 7 | 1.9 | 1.32 | 2 | 3.4 | 194 | 3851 | 654 | 30 |
| 2015 | T2-D | blk 3 | 5.9 | 6.7 | 2.7 | 1.36 | 20 | 14.5 | 289 | 3288 | 700 | 17 |
| 2015 | T3-E | blk 3 | 6.1 | 6.8 | 2.3 | 1.23 | 3 | 8.7 | 254 | 3065 | 693 | 16 |
| 2015 | T4-D | blk 3 | 5.9 | 6.7 | 2.1 | 1.17 | 2 | 6.2 | 202 | 2834 | 634 | 13 |
| 2015 | T6-C | blk 3 | 6.4 | 6.9 | 1.9 | 1.26 | 2 | 15.7 | 244 | 3672 | 835 | 14 |
| 2015 | T1-D | blk 4 | 5.9 | 6.7 | 2.4 | 1.33 | 3 | 7.6 | 242 | 3454 | 695 | 19 |
| 2015 | T2-A | blk 4 | 6.2 | 6.7 | 2.4 | 1.32 | 3 | 8.3 | 198 | 3362 | 672 | 23 |
| 2015 | T3-C | blk 4 | 6.2 | 6.5 | 2.2 | 1.31 | 4 | 9.7 | 263 | 3735 | 814 | 19 |
| 2015 | T4-B | blk 4 | 6.5 | 6.8 | 2.1 | 1.34 | 3 | 3.5 | 199 | 4002 | 592 | 15 |
| 2015 | T6-E | blk 4 | 5.8 | 6.6 | 2.2 | 1.27 | 2 | 5.4 | 202 | 3158 | 717 | 14 |
| 2015 | T1-C | blk 5 | 5.9 | 6.6 | 2.7 | 1.4 | 3 | 10.7 | 212 | 3281 | 623 | 24 |
| 2015 | T2-E | blk 5 | 6.1 | 6.6 | 2.5 | 1.23 | 1 | 7.9 | 213 | 3148 | 581 | 22 |
| 2015 | T3-D | blk 5 | 6 | 6.6 | 2.2 | 1.25 | 1 | 3.8 | 179 | 3660 | 589 | 19 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2015 | T4-A | blk 5 | 6.4 | 6.7 | 1.9 | 1.23 | 3 | 2.5 | 171 | 3116 | 717 | 15 |
| 2015 | T6-D | blk 5 | 5.8 | 6.6 | 2.3 | 1.25 | 6 | 9.4 | 215 | 3200 | 683 | 11 |
| 2016 | T1-E | blk 1 | 6.2 | 6.9 | 2.3 | 1.3 | 3 | 17.1 | 238 | 3817 | 870 | 38 |
| 2016 | T2-B | blk 1 | 6.3 | 6.8 | 2.6 | 1.26 | 1 | 22.3 | 300 | 3517 | 766 | 18 |
| 2016 | T3-A | blk 1 | 6.1 | 6.8 | 2.1 | 1.33 | 3 | 10.8 | 221 | 3507 | 723 | 24 |
| 2016 | T4-C | blk 1 | 6.3 | 6.8 | 2.6 | 1.17 | 2 | 19.7 | 192 | 3366 | 810 | 99 |
| 2016 | T6-A | blk 1 | 5.9 | 6.8 | 2.2 | 1.24 | 2 | 15.2 | 295 | 3510 | 725 | 16 |
| 2016 | T1-B | blk 2 | 6.4 | 6.9 | 2.1 | 1.31 | 3 | 19.7 | 194 | 3682 | 751 | 22 |
| 2016 | T2-C | blk 2 | 6.3 | 6.9 | 2.4 | 1.33 | 1 | 17.5 | 258 | 3575 | 783 | 17 |
| 2016 | T3-B | blk 2 | 5.6 | 6.7 | 2.3 | 1.28 | 4 | 22.2 | 273 | 3562 | 596 | 19 |
| 2016 | T4-E | blk 2 | 6.2 | 6.8 | 2 | 1.26 | 1 | 34.1 | 245 | 3817 | 821 | 24 |
| 2016 | T6-B | blk 2 | 6.2 | 6.9 | 2.3 | 1.31 | 3 | 35.2 | 235 | 3447 | 758 | 13 |
| 2016 | T1-A | blk 3 | 6.6 | 7.5 | 2 | 1.3 | 2 | 7 | 139 | 3785 | 645 | 26 |
| 2016 | T2-D | blk 3 | 6.1 | 6.8 | 2.6 | 1.3 | 2 | 18.6 | 258 | 3253 | 655 | 18 |
| 2016 | T3-E | blk 3 | 5.7 | 6.6 | 2.7 | 1.37 | 4 | 15.1 | 268 | 3628 | 736 | 16 |
| 2016 | T4-D | blk 3 | 6.2 | 6.8 | 2.5 | 1.34 | 3 | 17.2 | 256 | 3818 | 796 | 33 |
| 2016 | T6-C | blk 3 | 6 | 6.8 | 2.2 | 1.28 | 4 | 19.4 | 241 | 3626 | 777 | 15 |
| 2016 | T1-D | blk 4 | 5.8 | 6.7 | 2.5 | 1.33 | 24 | 11.8 | 265 | 3485 | 636 | 18 |
| 2016 | T2-A | blk 4 | 5.9 | 6.7 | 2.5 | 1.38 | 2 | 28.5 | 205 | 3426 | 691 | 23 |
| 2016 | T3-C | blk 4 | 6.3 | 6.9 | 2.1 | 1.23 | 5 | 11.7 | 234 | 3463 | 681 | 16 |
| 2016 | T4-B | blk 4 | 6.6 | 7.5 | 2 | 1.3 | 1 | 5.2 | 179 | 4231 | 571 | 22 |
| 2016 | T6-E | blk 4 | 5.9 | 6.7 | 2.3 | 1.26 | 2 | 16.4 | 231 | 3461 | 741 | 14 |
| 2016 | T1-C | blk 5 | 6 | 6.8 | 2.6 | 1.37 | 5 | 19.5 | 256 | 3425 | 562 | 21 |
| 2016 | T2-E | blk 5 | 6 | 6.6 | 2.9 | 1.37 | 3 | 30.9 | 270 | 3779 | 650 | 18 |
| 2016 | T3-D | blk 5 | 6.3 | 6.9 | 2.4 | 1.29 | 1 | 4.2 | 195 | 3734 | 545 | 19 |
| 2016 | T4-A | blk 5 | 6.6 | 7.5 | 1.9 | 1.23 | 1 | 9.4 | 181 | 3371 | 718 | 24 |
| 2016 | T6-D | blk 5 | 5.9 | 6.7 | 2.6 | 1.36 | 2 | 7.3 | 218 | 3677 | 721 | 15 |
| 2017 | T1-E | blk 1 | 6.4 | 6.9 | 2.5 | 1.36 | 5 | 16.2 | 244 | 3897 | 887 | 48 |
| 2017 | T2-B | blk 1 | 6.1 | 6.7 | 2.5 | 1.21 | 1 | 17.5 | 277 | 2851 | 644 | 16 |
| 2017 | T3-A | blk 1 | 5.8 | 6.8 | 2.5 | 1.06 | 3 | 16.4 | 169 | 2390 | 497 | 18 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 | T4-C | blk 1 | 6.2 | 6.7 | 2.2 | 1.21 | 1 | 21.6 | 211 | 3001 | 744 | 115 |
| 2017 | T6-A | blk 1 | 6.2 | 6.8 | 2 | 1.24 | 1 | 16 | 224 | 3036 | 656 | 13 |
| 2017 | T1-B | blk 2 | 6 | 6.8 | 2.2 | 1.33 | 8 | 26.6 | 230 | 3039 | 615 | 22 |
| 2017 | T2-C | blk 2 | 6.4 | 6.8 | 2.2 | 1.25 | 1 | 25 | 240 | 3301 | 701 | 19 |
| 2017 | T3-B | blk 2 | 6 | 6.8 | 2.4 | 1.18 | 2 | 20 | 207 | 2944 | 530 | 17 |
| 2017 | T4-E | blk 2 | 6.3 | 7 | 2.2 | 1.09 | 1 | 24.1 | 170 | 2486 | 522 | 17 |
| 2017 | T6-B | blk 2 | 6.4 | 6.9 | 2 | 1.17 | 1 | 25.2 | 239 | 3219 | 722 | 15 |
| 2017 | T1-A | blk 3 | 6.2 | 6.9 | 1.9 | 1.24 | 3 | 9.2 | 168 | 3119 | 495 | 26 |
| 2017 | T2-D | blk 3 | 6.1 | 6.8 | 2.6 | 1.31 | 1 | 20.7 | 247 | 2888 | 526 | 18 |
| 2017 | T3-E | blk 3 | 6.4 | 7 | 2.9 | 1.02 | 4 | 26.9 | 252 | 2640 | 505 | 12 |
| 2017 | T4-D | blk 3 | 6 | 6.8 | 2.3 | 1.17 | 1 | 14.8 | 209 | 2764 | 582 | 19 |
| 2017 | T6-C | blk 3 | 6.2 | 6.8 | 1.9 | 1.22 | 1 | 16.1 | 190 | 2942 | 643 | 15 |
| 2017 | T1-D | blk 4 | 5.8 | 6.7 | 2.3 | 1.28 | 10 | 10.4 | 210 | 3034 | 544 | 18 |
| 2017 | T2-A | blk 4 | 5.9 | 6.8 | 2.5 | 1.14 | 1 | 16.5 | 146 | 2346 | 467 | 16 |
| 2017 | T3-C | blk 4 | 6.3 | 6.9 | 2.3 | 1.19 | 4 | 16.4 | 182 | 2903 | 568 | 15 |
| 2017 | T4-B | blk 4 | 6.6 | 7.5 | 2.1 | 1.34 | 1 | 8.1 | 185 | 3625 | 485 | 22 |
| 2017 | T6-E | blk 4 | 6 | 6.6 | 2.2 | 1.27 | 1 | 16 | 204 | 3138 | 643 | 15 |
| 2017 | T1-C | blk 5 | 5.8 | 6.8 | 2.6 | 1.09 | 14 | 28.1 | 151 | 2289 | 405 | 17 |
| 2017 | T2-E | blk 5 | 5.9 | 6.7 | 2.6 | 1.32 | 2 | 23.4 | 222 | 3238 | 547 | 21 |
| 2017 | T3-D | blk 5 | 6.2 | 6.8 | 2.2 | 1.22 | 3 | 5.6 | 163 | 3448 | 491 | 24 |
| 2017 | T4-A | blk 5 | 6.4 | 6.8 | 2 | 1.18 | 1 | 30.1 | 166 | 3103 | 626 | 22 |
| 2017 | T6-D | blk 5 | 6 | 6.8 | 2.4 | 1.02 | 2 | 8.8 | 160 | 2535 | 521 | 14 |

| **Year** | **Trt** | **Block** | **S ppm** | **Zn ppm** | **% K** | **% Mg** | **% Ca** | **% Na** | **% H** | **CEC** | **Soluble Salts mmhos/cm** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2015 | T1-E | blk 1 | 11 | 0.3 | 2.1 | 25.7 | 64.1 | 0.6 | 7.6 | 31.7 | 0.42 |
| 2015 | T2-B | blk 1 | 5 | 0.4 | 2.7 | 23.3 | 59.1 | 0.3 | 14.7 | 27.3 | 0.34 |
| 2015 | T3-A | blk 1 | 6 | 0.7 | 2.1 | 20.4 | 57.5 | 0.3 | 19.7 | 25.4 | 0.33 |
| 2015 | T4-C | blk 1 | 4 | 0.2 | 1.8 | 26.2 | 57.6 | 1.8 | 12.6 | 31.8 | 0.46 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2015 | T6-A | blk 1 | 4 | 0.6 | 2.5 | 22.9 | 60.2 | 0.2 | 14.2 | 28.2 | 0.36 |
| 2015 | T1-B | blk 2 | 11 | 0.3 | 2.3 | 23.1 | 66.8 | 0.4 | 7.4 | 27 | 0.36 |
| 2015 | T2-C | blk 2 | 6 | 0.2 | 2.2 | 23.8 | 59.2 | 0.3 | 14.4 | 27.8 | 0.35 |
| 2015 | T3-B | blk 2 | 6 | 0.3 | 1.9 | 19.4 | 64.4 | 0.3 | 14 | 28.7 | 0.36 |
| 2015 | T4-E | blk 2 | 3 | 0.1 | 2.1 | 24.2 | 61.4 | 0.3 | 12 | 25 | 0.31 |
| 2015 | T6-B | blk 2 | 2 | 0.2 | 2.3 | 25.3 | 61.6 | 0.2 | 10.7 | 28.1 | 0.34 |
| 2015 | T1-A | blk 3 | 14 | 0.1 | 1.8 | 19.9 | 70.4 | 0.5 | 7.3 | 27.3 | 0.38 |
| 2015 | T2-D | blk 3 | 7 | 1 | 2.7 | 21.5 | 60.7 | 0.3 | 14.8 | 27.1 | 0.43 |
| 2015 | T3-E | blk 3 | 6 | 0.7 | 2.6 | 23.3 | 61.7 | 0.3 | 12.1 | 24.8 | 0.32 |
| 2015 | T4-D | blk 3 | 6 | 0.3 | 2.2 | 22 | 59 | 0.2 | 16.6 | 24 | 0.31 |
| 2015 | T6-C | blk 3 | 3 | 0.4 | 2.2 | 24.5 | 64.6 | 0.2 | 8.4 | 28.4 | 0.35 |
| 2015 | T1-D | blk 4 | 7 | 0.6 | 2.2 | 20.9 | 62.2 | 0.3 | 14.4 | 27.8 | 0.36 |
| 2015 | T2-A | blk 4 | 8 | 0.7 | 1.9 | 20.7 | 62.2 | 0.4 | 14.8 | 27 | 0.36 |
| 2015 | T3-C | blk 4 | 4 | 0.5 | 2.1 | 21.1 | 58 | 0.3 | 18.6 | 32.2 | 0.4 |
| 2015 | T4-B | blk 4 | 4 | 0.1 | 1.8 | 17.3 | 70.2 | 0.2 | 10.5 | 28.5 | 0.36 |
| 2015 | T6-E | blk 4 | 4 | 0.1 | 1.9 | 21.9 | 57.7 | 0.2 | 18.3 | 27.3 | 0.34 |
| 2015 | T1-C | blk 5 | 9 | 1.5 | 2 | 19.1 | 60.2 | 0.4 | 18.4 | 27.2 | 0.37 |
| 2015 | T2-E | blk 5 | 8 | 1.1 | 2.1 | 18.5 | 60 | 0.4 | 19.1 | 26.2 | 0.34 |
| 2015 | T3-D | blk 5 | 6 | 0.1 | 1.6 | 17.1 | 63.7 | 0.3 | 17.4 | 28.7 | 0.36 |
| 2015 | T4-A | blk 5 | 7 | 0.1 | 1.7 | 22.9 | 59.8 | 0.3 | 15.3 | 26.1 | 0.34 |
| 2015 | T6-D | blk 5 | 6 | 0.2 | 2 | 20.9 | 58.6 | 0.2 | 18.3 | 27.3 | 0.36 |
| 2016 | T1-E | blk 1 | 10 | 3.1 | 2.1 | 24.6 | 64.7 | 0.6 | 8.1 | 29.5 | 0.4 |
| 2016 | T2-B | blk 1 | 11 | 2.2 | 2.8 | 22.9 | 63.2 | 0.3 | 10.8 | 27.8 | 0.36 |
| 2016 | T3-A | blk 1 | 10 | 3.8 | 2.1 | 22.1 | 64.4 | 0.4 | 11 | 27.2 | 0.37 |
| 2016 | T4-C | blk 1 | 11 | 2.1 | 1.8 | 24.5 | 61.2 | 1.6 | 10.9 | 27.5 | 0.42 |
| 2016 | T6-A | blk 1 | 10 | 2.9 | 2.8 | 22 | 64 | 0.3 | 10.9 | 27.4 | 0.36 |
| 2016 | T1-B | blk 2 | 10 | 1.3 | 1.8 | 22.6 | 66.6 | 0.3 | 8.7 | 27.7 | 0.37 |
| 2016 | T2-C | blk 2 | 10 | 4.5 | 2.4 | 23.7 | 64.9 | 0.3 | 8.7 | 27.5 | 0.36 |
| 2016 | T3-B | blk 2 | 13 | 4.1 | 2.5 | 18 | 64.6 | 0.3 | 14.5 | 27.6 | 0.38 |
| 2016 | T4-E | blk 2 | 9 | 5.3 | 2.1 | 23.1 | 64.3 | 0.4 | 10.1 | 29.7 | 0.38 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2016 | T6-B | blk 2 | 14 | 2.5 | 2.3 | 23.7 | 64.8 | 0.2 | 9 | 26.6 | 0.37 |
| 2016 | T1-A | blk 3 | 12 | 0.7 | 1.4 | 21.7 | 76.4 | 0.5 | 0 | 24.8 | 0.34 |
| 2016 | T2-D | blk 3 | 11 | 2.6 | 2.6 | 21.4 | 63.9 | 0.3 | 11.8 | 25.5 | 0.34 |
| 2016 | T3-E | blk 3 | 10 | 1.7 | 2.3 | 20.4 | 60.4 | 0.2 | 16.6 | 30 | 0.39 |
| 2016 | T4-D | blk 3 | 10 | 2.3 | 2.2 | 22.5 | 64.7 | 0.5 | 10.2 | 29.5 | 0.4 |
| 2016 | T6-C | blk 3 | 9 | 7.1 | 2.2 | 22.9 | 64.1 | 0.2 | 10.6 | 28.3 | 0.37 |
| 2016 | T1-D | blk 4 | 11 | 3.3 | 2.5 | 19.3 | 63.4 | 0.3 | 14.6 | 27.5 | 0.46 |
| 2016 | T2-A | blk 4 | 15 | 2.6 | 1.9 | 20.9 | 62.3 | 0.4 | 14.5 | 27.5 | 0.38 |
| 2016 | T3-C | blk 4 | 9 | 1.5 | 2.3 | 21.8 | 66.4 | 0.3 | 9.2 | 26.1 | 0.36 |
| 2016 | T4-B | blk 4 | 8 | 0.6 | 1.7 | 18 | 79.9 | 0.4 | 0 | 26.5 | 0.34 |
| 2016 | T6-E | blk 4 | 10 | 3.9 | 2.1 | 21.9 | 61.5 | 0.2 | 14.2 | 28.1 | 0.37 |
| 2016 | T1-C | blk 5 | 12 | 7.3 | 2.6 | 18.3 | 67 | 0.4 | 11.7 | 25.6 | 0.36 |
| 2016 | T2-E | blk 5 | 12 | 3.2 | 2.3 | 18 | 62.8 | 0.3 | 16.6 | 30.1 | 0.4 |
| 2016 | T3-D | blk 5 | 6 | 0.7 | 1.9 | 17.3 | 71.3 | 0.3 | 9.2 | 26.2 | 0.33 |
| 2016 | T4-A | blk 5 | 12 | 1.8 | 2 | 25.6 | 72 | 0.4 | 0 | 23.4 | 0.33 |
| 2016 | T6-D | blk 5 | 7 | 0.8 | 1.9 | 20.7 | 63.4 | 0.2 | 13.8 | 29 | 0.37 |
| 2017 | T1-E | blk 1 | 10 | 3.4 | 2.1 | 24.5 | 64.6 | 0.7 | 8.1 | 30.2 | 0.42 |
| 2017 | T2-B | blk 1 | 9 | 2 | 2.9 | 21.8 | 58 | 0.3 | 16.9 | 24.6 | 0.32 |
| 2017 | T3-A | blk 1 | 9 | 1.9 | 2.2 | 21 | 60.5 | 0.4 | 15.9 | 19.8 | 0.28 |
| 2017 | T4-C | blk 1 | 10 | 2 | 2.1 | 24 | 58.1 | 1.9 | 13.9 | 25.8 | 0.4 |
| 2017 | T6-A | blk 1 | 8 | 1.9 | 2.4 | 22.8 | 63.4 | 0.2 | 11.1 | 23.9 | 0.31 |
| 2017 | T1-B | blk 2 | 10 | 3.9 | 2.5 | 21.6 | 64.1 | 0.4 | 11.4 | 23.7 | 0.35 |
| 2017 | T2-C | blk 2 | 9 | 1.8 | 2.4 | 22.8 | 64.3 | 0.3 | 10.2 | 25.7 | 0.34 |
| 2017 | T3-B | blk 2 | 9 | 4.5 | 2.4 | 19.7 | 65.6 | 0.3 | 12 | 22.4 | 0.31 |
| 2017 | T4-E | blk 2 | 9 | 1.6 | 2.2 | 22.4 | 64 | 0.4 | 11 | 19.4 | 0.27 |
| 2017 | T6-B | blk 2 | 11 | 6.4 | 2.4 | 24 | 64.1 | 0.3 | 9.3 | 25.1 | 0.33 |
| 2017 | T1-A | blk 3 | 11 | 4.1 | 1.9 | 18.2 | 68.8 | 0.5 | 10.7 | 22.7 | 0.33 |
| 2017 | T2-D | blk 3 | 10 | 1.9 | 2.8 | 19.2 | 63.2 | 0.3 | 14.5 | 22.8 | 0.31 |
| 2017 | T3-E | blk 3 | 8 | 2.3 | 3.2 | 20.8 | 65.1 | 0.3 | 10.7 | 20.3 | 0.29 |
| 2017 | T4-D | blk 3 | 8 | 3.6 | 2.4 | 21.4 | 60.9 | 0.4 | 14.9 | 22.7 | 0.3 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017 | T6-C | blk 3 | 7 | 1.9 | 2.1 | 23 | 63 | 0.3 | 11.7 | 23.3 | 0.31 |
| 2017 | T1-D | blk 4 | 8 | 4.3 | 2.2 | 18.5 | 61.7 | 0.3 | 17.3 | 24.6 | 0.36 |
| 2017 | T2-A | blk 4 | 10 | 6.1 | 1.9 | 19.9 | 60.1 | 0.4 | 17.7 | 19.5 | 0.27 |
| 2017 | T3-C | blk 4 | 9 | 3.7 | 2.1 | 21.4 | 65.5 | 0.3 | 10.8 | 22.2 | 0.31 |
| 2017 | T4-B | blk 4 | 8 | 1 | 2.1 | 17.8 | 79.7 | 0.4 | 0 | 22.7 | 0.31 |
| 2017 | T6-E | blk 4 | 10 | 2 | 2 | 20.3 | 59.4 | 0.2 | 18.1 | 26.4 | 0.34 |
| 2017 | T1-C | blk 5 | 8 | 3.8 | 2.1 | 18.3 | 62 | 0.4 | 17.2 | 18.5 | 0.31 |
| 2017 | T2-E | blk 5 | 12 | 2.6 | 2.2 | 17.7 | 62.7 | 0.4 | 17 | 25.8 | 0.35 |
| 2017 | T3-D | blk 5 | 10 | 2.8 | 1.7 | 16.2 | 68.4 | 0.4 | 13.3 | 25.2 | 0.34 |
| 2017 | T4-A | blk 5 | 11 | 1.4 | 1.8 | 21.7 | 64.6 | 0.4 | 11.4 | 24 | 0.33 |
| 2017 | T6-D | blk 5 | 9 | 1.3 | 2 | 21.2 | 61.9 | 0.3 | 14.6 | 20.5 | 0.28 |

**APPENDIX N.** 2017 Petiole Samples

| Year | Treatment | Nitrate (ppm) | Phosphorus (%) | Potassium (%) | Magnesium (%) | Calcium (%) | Sodium (%) | Sulfur (%) |
|---|---|---|---|---|---|---|---|---|
| 2017 | Trt 1 | 160.1 | 0.32 | 3.96 | 0.25 | 1.11 | 0.03 | 0.1 |
| 2017 | Trt 2 | 61.9 | 0.49 | 4.02 | 0.18 | 1.45 | 0.03 | 0.08 |
| 2017 | Trt 3 | 41.2 | 0.42 | 4.36 | 0.23 | 1.15 | 0.02 | 0.08 |
| 2017 | Trt 4 | 1.2 | 0.5 | 3.83 | 0.15 | 1.35 | 0.03 | 0.07 |
| 2017 | Trt 6 | 26 | 0.51 | 3.89 | 0.19 | 1.3 | 0.02 | 0.09 |
| | | | | | | | | |
| **Year** | **Treatment** | **Zinc (ppm)** | **Manganese (ppm)** | **Copper (ppm)** | **Iron (ppm)** | **Boron (ppm)** | **Aluminum (ppm)** | |
| 2017 | Trt 1 | 42.49 | 76.2 | 10.7 | 36.7 | 33 | 24.9 | |
| 2017 | Trt 2 | 48.49 | 77.8 | 8.3 | 30.5 | 33.7 | 19.3 | |
| 2017 | Trt 3 | 42.42 | 74.1 | 9.2 | 31.4 | 31 | 19.1 | |
| 2017 | Trt 4 | 45.84 | 88.4 | 7.8 | 29.9 | 33.5 | 17 | |
| 2017 | Trt 6 | 49.28 | 90.6 | 8.9 | 34 | 32.9 | 19.6 | |

**APPENDIX O.** Data for Greenhouse Estimation of Leaf Water Potential

| Treatment | Time | Air Temp °F | Air Temp °C | Relative Humidity | Irradiance (w/m2) | LWP | S65 CWSI | C2 CWSI |
|---|---|---|---|---|---|---|---|---|
| **C-1** | 10:50 | 95.30 | 35.17 | 42.00 | 344.00 | 9.00 | -0.02 | -1.35 |
| **C-2** | 11:21 | 96.60 | 35.89 | 41.00 | 770.00 | 7.60 | 0.16 | 0.23 |
| **C-3** | 11:25 | 96.00 | 35.56 | 40.00 | 750.00 | 10.20 | 0.20 | 0.56 |
| **C-4** | 12:09 | 98.90 | 37.17 | 37.00 | 668.00 | 9.00 | 0.04 | 0.19 |
| **C-5** | 12:29 | 96.20 | 35.67 | 36.00 | 147.00 | 7.00 | -0.02 | -0.54 |
| **C-6** | 12:57 | 97.30 | 36.28 | 35.00 | 878.00 | 9.40 | -0.43 | -0.41 |
| **2-1** | 10:54 | 95.30 | 35.17 | 42.00 | 318.00 | 10.30 | -1.14 | -4.33 |
| **2-2** | 11:23 | 95.90 | 35.50 | 40.00 | 747.00 | 10.80 | -0.01 | -0.01 |
| **2-3** | 11:47 | 98.00 | 36.67 | 38.00 | 746.00 | 11.80 | 0.01 | 0.29 |
| **2-4** | 12:11 | 98.40 | 36.89 | 37.00 | 588.00 | 12.00 | 0.28 | 0.07 |
| **2-5** | 12:32 | 95.90 | 35.50 | 36.00 | 225.00 | 9.00 | 0.00 | -0.28 |
| **2-6** | 1:00 | 97.50 | 36.39 | 35.00 | 859.00 | 9.80 | -0.32 | -0.25 |
| **4-1** | 10:57 | 94.10 | 34.50 | 42.00 | 302.00 | 12.00 | -0.56 | -0.27 |
| **4-2** | 11:31 | 96.90 | 36.06 | 41.00 | 768.00 | 12.40 | -0.18 | 0.50 |
| **4-3** | 11:50 | 98.60 | 37.00 | 38.00 | 681.00 | 11.80 | 0.66 | 0.50 |
| **4-4** | 12:13 | 97.70 | 36.50 | 37.00 | 483.00 | 9.00 | 0.32 | 0.60 |
| **4-5** | 12:35 | 95.50 | 35.28 | 38.00 | 440.00 | 8.40 | 0.20 | 0.55 |
| **4-6** | 1:02 | 97.50 | 36.39 | 37.00 | 759.00 | 11.00 | -0.34 | 0.34 |
| **6-1** | 11:01 | 93.30 | 34.06 | 42.00 | 331.00 | 9.20 | 0.12 | 0.68 |
| **6-2** | 11:34 | 97.10 | 36.17 | 40.00 | 763.00 | 10.80 | -0.15 | -0.11 |
| **6-3** | 11:52 | 98.90 | 37.17 | 39.00 | 574.00 | 8.00 | 0.30 | 0.32 |
| **6-4** | 12:15 | 97.30 | 36.28 | 36.00 | 386.00 | 10.00 | 0.67 | 0.76 |
| **6-5** | 12:41 | 95.00 | 35.00 | 36.00 | 792.00 | 11.20 | 0.08 | 0.26 |
| **6-6** | 1:04 | 97.70 | 36.50 | 36.00 | 877.00 | 10.40 | 0.38 | 0.10 |
| **8-1** | 11:04 | 93.20 | 34.00 | 41.00 | 360.00 | 12.20 | 0.62 | 0.63 |
| **8-2** | 11:37 | 97.30 | 36.28 | 38.00 | 769.00 | 11.00 | 0.49 | 0.18 |
| **8-3** | 12:38 | 95.30 | 35.17 | 36.00 | 685.00 | 12.00 | -0.02 | 0.63 |
| **8-4** | 12:18 | 97.10 | 36.17 | 36.00 | 490.00 | 12.60 | 0.38 | 0.71 |
| **8-5** | 12:43 | 95.30 | 35.17 | 37.00 | 831.00 | 11.40 | 0.68 | 0.81 |
| **8-6** | 1:07 | 97.80 | 36.56 | 37.00 | 915.00 | 13.00 | 0.21 | 1.23 |
| **10-1** | 11:06 | 93.50 | 34.17 | 42.00 | 435.00 | 12.20 | 0.73 | 0.96 |
| **10-2** | 11:39 | 97.30 | 36.28 | 39.00 | 794.00 | 10.80 | 0.38 | 0.52 |
| **10-3** | 11:58 | 99.50 | 37.50 | 39.00 | 379.00 | 10.40 | 0.35 | 0.60 |
| **10-4** | 12:21 | 97.30 | 36.28 | 36.00 | 339.00 | 10.60 | 0.25 | 0.54 |
| **10-5** | 12:46 | 95.00 | 35.00 | 35.00 | 829.00 | 10.20 | 0.18 | 0.07 |
| **10-6** | 1:11 | 98.40 | 36.89 | 36.00 | 1019.00 | 10.20 | 0.31 | 0.90 |
| **12-1** | 11:09 | 94.10 | 34.50 | 41.00 | 545.00 | 12.40 | -0.01 | 0.48 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **12-2** | 11:42 | 97.50 | 36.39 | 40.00 | 781.00 | 12.60 | 0.08 | 0.34 |
| **12-3** | 12:01 | 99.10 | 37.28 | 39.00 | 806.00 | 12.00 | 0.53 | 0.89 |
| **12-4** | 12:24 | 97.10 | 36.17 | 36.00 | 216.00 | 13.00 | 0.51 | 1.02 |
| **12-5** | 12:48 | 95.50 | 35.28 | 35.00 | 842.00 | 14.20 | 0.45 | 0.26 |
| **12-6** | 1:13 | 98.70 | 37.06 | 36.00 | 1065.00 | 12.00 | 0.41 | 1.23 |
| **14-1** | 11:13 | 94.40 | 34.67 | 40.00 | 639.00 | 14.20 | 0.65 | 2.02 |
| **14-2** | 11:44 | 97.10 | 36.17 | 40.00 | 767.00 | 13.60 | 0.57 | 0.71 |
| **14-3** | 12:03 | 99.80 | 37.67 | 37.00 | 806.00 | 17.20 | 0.36 | 0.88 |
| **14-4** | 12:27 | 96.80 | 36.00 | 36.00 | 157.00 | 10.60 | 0.48 | 1.08 |
| **14-5** | 12:51 | 96.20 | 35.67 | 35.00 | 872.00 | 12.40 | 0.08 | 0.01 |
| **14-6** | 1:15 | 98.70 | 37.06 | 35.00 | 1034.00 | 12.20 | 0.61 | 0.41 |